# GENERAL SCIENCE

## PART II

G. Bell and Sons Ltd
Portugal Street, London, W.C. 2

*Calcutta, Bombay & Madras*
Longmans Green & Co. Ltd

*Toronto*
Clarke, Irwin & Co. Ltd

# GENERAL SCIENCE

## PART II

BY

F. FAIRBROTHER, M.Sc.

HEADMASTER OF THE CEDARS SCHOOL, LEIGHTON BUZZARD

E. NIGHTINGALE, M.Sc.

SENIOR SCIENCE MASTER AT ST ALBANS SCHOOI

AND

F. J. WYETH, M.A., Sc.D. (Cantab), D.Sc. (Lond.)

FORMERLY HEADMASTER OF NEWPORT SCHOOL, ESSEX

LONDON

G. BELL AND SONS, LTD

*Sixth Impression*
*First published* 1933

Printed in Great Britain by
NEILL & CO., LTD., EDINBURGH.

# PREFACE

This is the second volume of a series of four designed to include the basic principles of physics, chemistry, and biology. The authors aim at broadening the pupil's outlook by dealing with the elementary principles of these subjects, not only from the purely scientific standpoint, but also in their application to everyday things. In this way they hope that the study of science will exert a humanising influence on the pupil. At the same time they claim that in such a course one can train the pupil in scientific habits of thought.

The present volume develops the physics and chemistry of Part I and introduces the pupil to the study of biology. The course should normally be taken at ages twelve to thirteen plus.

After performing the experiments, students should write a clear connected account, with sketches where necessary, answering the questions as they arise. Disconnected notes must be discouraged.

The authors have endeavoured to stress the *unity* of Biology and have emphasised, more than is usual, *function*, especially as regards *animal* physiology. A series of microscope slides for use in the course has been specially prepared, and may be obtained for £1, post free, from Mr C. Biddolph, Zoological Department, King's College, Strand, London, W.C. 2. These may be thrown on to a screen from one of the many cheap micro-projectors now on the market. In this way some members of the class may study the slides whilst others are examining the living animals and plants through microscopes.

Specimens of Amœba, Hydra, etc. may be obtained fresh as required and at small cost from one of the firms which specialises in biological requirements, or from Mr Biddolph.

The authors are indebted to certain sources for some of the illustrations, for which due acknowledgment is made in the text. They would also like to thank Mr R. Jeffery, M.A., and Miss K. K. Dawson, M.Sc., of the Cedars School, Leighton Buzzard, and Mr B. M. Neville, B.Sc., of William Ellis School, London, for kindly reading the MS. and proofs, and for making valuable suggestions.

*April* 1933

# CONTENTS


| CHAP. | | PAGE |
|---|---|---|
| I. | The Chemical Balance. Deliquescent, Efflorescent, and Hygroscopic Substances | 1 |
| II. | Elements, Mixtures, Compounds. Hydrogen and Water | 9 |
| III. | The Common Mineral Acids. Preparation of Salts | 19 |
| IV. | Chalk, Quicklime, Limewater. Hard and Soft Waters | 27 |
| V. | Heat and Temperature | 43 |
| VI. | Latent Heat. The Steam-Engine | 51 |
| VII. | Thermal Capacity and Specific Heat | 59 |
| VIII. | Modes of Transmission of Heat. Applications to Everyday Life | 71 |
| IX. | Heat and Energy | 86 |
| X. | Introduction to Biology. Properties of Living Organisms | 93 |
| XI. | Two Simple Living Organisms: Amœba (an Animal) and Chlamydomonas (a Plant) | 97 |
| XII. | The Cell. Tissues. Two Simple Multicellular Organisms: Hydra (an Animal) and Spirogyra (a Green Plant). The Shepherd's Purse | 108 |
| XIII. | Irritability | 131 |
| XIV. | Movement | 139 |
| XV. | Some of the Chief Kinds of Movement | 166 |
| | Answers to Numerical Examples | 178 |
| | Index | 179 |

# GENERAL SCIENCE

## PART II

### CHAPTER I

### THE CHEMICAL BALANCE. DELIQUESCENT, EFFLORESCENT, AND HYGROSCOPIC SUBSTANCES

HITHERTO you have used spring balances as a quick and convenient method of weighing. Some of the experiments you will be required to perform in the future will require more accurate weighing than is possible with a spring balance.

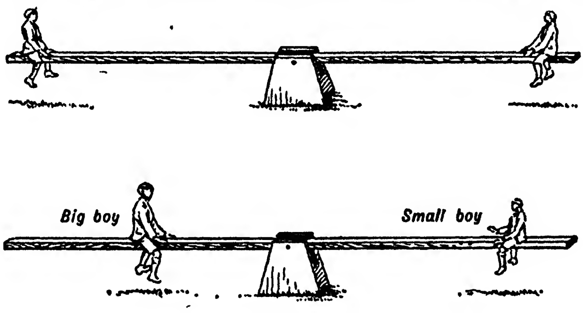



FIG. 1.

You are familiar with the see-saw (fig. 1), which is a plank of wood pivoted at its point of balance Supposing that you sat at one end of a see-saw, *where would another boy of equal weight have to sit to balance you? What would happen if a boy of twice your weight were to sit at the other end of the see-saw? Where do you think this boy should sit in order to balance you?* There may be some simple relation between balancing weights

and their distances from the pivot. In order to find out this relation perform the following experiment, in which known weights are hung from a model see-saw in such a way that their distances may be accurately measured.

**A Laboratory Experiment with a Model See-Saw**—Loop a piece of cotton tightly round a metre or half-metre ruler and suspend it from a hook or a retort stand (fig. 2). Push

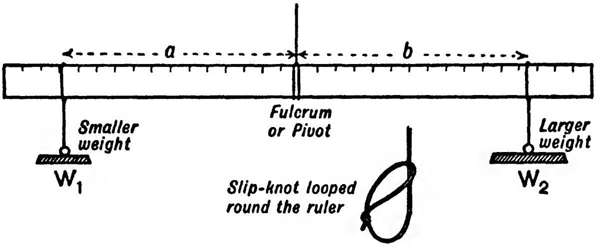



FIG. 2.

the ruler through the loop until it is balanced and make a careful note of its position. *The suspending cotton loop must not be moved during the experiment.* Hang two weights $W_1$ and $W_2$ as shown. Suppose $W_1$ is 50 grm. Hang it, say, 20 cm. from the fulcrum or pivot. Move the weight $W_2$ (say 50 grm.) until the ruler is balanced. Note the distances $a$ and $b$. Repeat the experiment with (i) the same weights and different distances, (ii) different weights at different distances (you can tie two or more weights together for this). Tabulate your results as follows :—

| Left-hand side | | | Right-hand side | | |
|---|---|---|---|---|---|
| $W_1$ | $a$ | $W_1 \times a$ | $W_2$ | $b$ | $W_2 \times b$ |
| grm. | cm. | grm. - cm. | grm. | cm. | grm. - cm. |
| | | | | | |

*What do you notice about the products* $W_1 a$ *and* $W_2 b$*?*

The balanced ruler is called a **lever.** The experiment shows that **the product of the weight and its distance from the pivot is the same for each side of a balanced lever.** This product is called the **leverage,** or **moment,** and measures the **turning effect of the weight about the pivot.** *If the weights* $W_1$ *and* $W_2$ *are equal, what relation must there be between the arms, a and b?* This is the principle of the **beam balance,** which is a balanced lever with equal arms. You must therefore

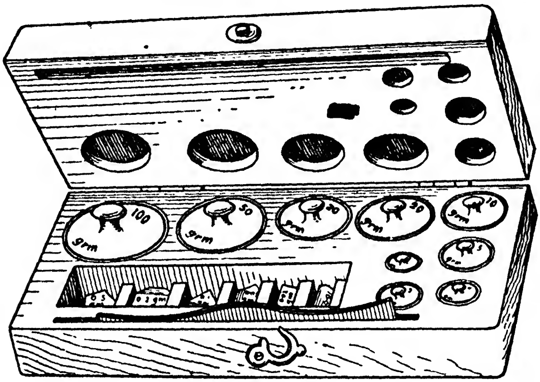



FIG. 3.

become familiar with the beam (or chemical) balance and the box of weights to be used with it.

Examine the box of weights (fig. 3) and **always lift them with the forceps.** Note first the value of the brass weights, starting with the biggest. Most boxes of weights have a common arrangement of 100 grm., 50 grm., 20 grm., 20 grm., 10 grm., 5 grm., 2 grm., 2 grm., 1 grm. By means of these weights alone you can get any weight from 1 grm. to 210 grm. Select weights to give, say, 157 grm., 84 grm., 59 grm., 8 grm., etc. Now examine the small weights. These are decimal portions of 1 grm., and are usually arranged as follows: 0·5 grm., 0·2 grm., 0·2 grm., 0·1 grm., 0·05 grm., 0·02 grm., 0·02 grm., 0·01 grm. Sometimes the 0·5 grm. weight has 500 mgrm. stamped on it (500 milli-

grams = 0·5 grm.), but it is better to learn the values as decimals of 1 grm., as all your weighings will be expressed in grams. Familiarise yourself with the shapes of the weights of different values (fig. 4).

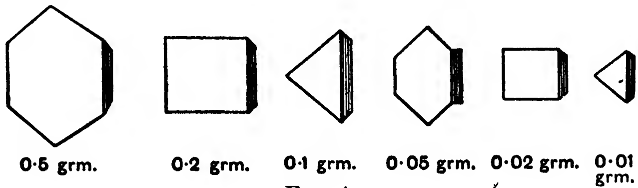



FIG. 4.

Now find the weights necessary for the following :—

25·55 grm., 13·73 grm., 27·84 grm., 31·46 grm.

The balance (see fig. 5) consists of a beam (fig. 6) supported on a knife edge and carrying a pointer rigidly attached to it. This pointer indicates whether the beam is horizontal or not. The beam carries two scale-pans suspended from hooks which are also supported on knife edges (fig. 7 (*a*), (*b*), (*c*)). The beam, and therefore the scale-pans, may be raised or lowered by means of a lever in front (or at the side) of the balance case. This lever raises a rod inside the vertical brass tube AB, fig. 5, and so lifts the beam at its knife-edge support.

The balance is a delicate instrument and must be used with the greatest possible care. It is used for measuring the weight of a body by balancing it with weights of known value.

**The following rules must be observed when weighing :—**

(1) Test the balance before use. To do this raise the pans and note if the beam comes to rest horizontally. If it does not, report before trying to correct it yourself.

*Why is it necessary to see if the beam comes to rest in a horizontal position before using the balance? Can you suggest any use for the little weights which can be moved along the screw threads attached to the beam?*

(2) See that the article to be weighed is clean and dry.

(3) Place the substance to be weighed in the left-hand pan and the weights in the right-hand pan.

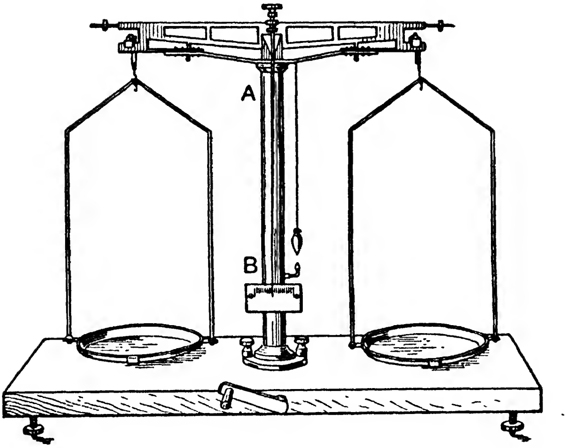



FIG. 5.

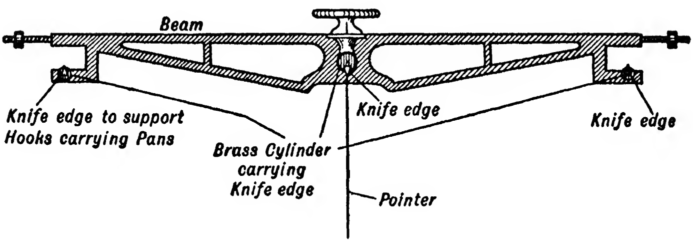



FIG. 6.

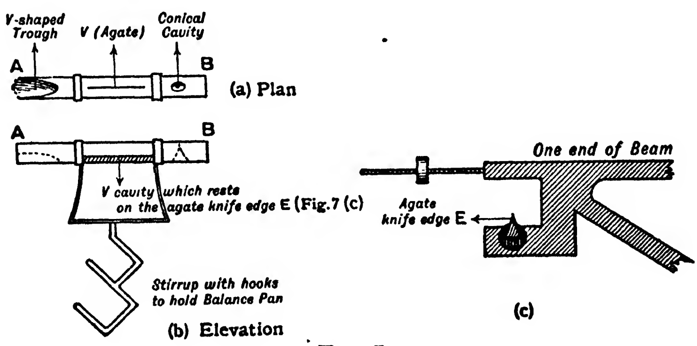



FIG. 7.

(4) Put on the pan a weight which you think will be just too large for the particular object you are weighing. Raise the pans. If the weight is too large, lower the pans, take off the weight and replace it by the next smaller; if too small, lower the pans, take off the weight and replace it by the next larger.

**Always find a weight which is too large before proceeding with the weighing; otherwise much time may be wasted.**

(5) Never add or remove weights from the pans when they are raised.

(6) Always lower the pans gently.

(7) Replace the weights in their correct places in the box immediately after use, always handling them with the forceps. Check the weight of the object as you do this.

(8) Never weigh anything heavier than the maximum load the balance is supposed to carry (generally 250 grm. for ordinary student balances).

A little practice will make weighing on this balance a simple matter. Weigh the 2 cm. cubes supplied and tabulate results.

| Cube | Weight as determined by the beam balance |
|---|---|
| Copper . . . | grm. |
| Tin . . . | |
| Iron . . . | |
| Wood . . . | |
| Brass . . . | |

## Deliquescent Substances. Efflorescent Substances. Hygroscopic Substances

### Experiment 1

On separate weighed watch-glasses weigh small pieces of (*a*) Caustic Soda, (*b*) Caustic Potash, (*c*) Calcium Chloride,

(*d*) Phosphorus Pentoxide, (*e*) clear crystals of washing soda, (*f*) clear crystals of alum, (*g*) clear crystals of sodium sulphate.

Leave exposed to the air for a day or so and then examine carefully. *What do you observe in each case?* Weigh again and note whether there has been a gain or loss in weight. *Can you suggest what has happened in each case?*

**Experiment 2**

Weigh an evaporating basin. Pour in a little concentrated sulphuric acid and reweigh. Leave this exposed to damp air for several hours. *Has there been any change in appearance? Has there been any change in weight?*

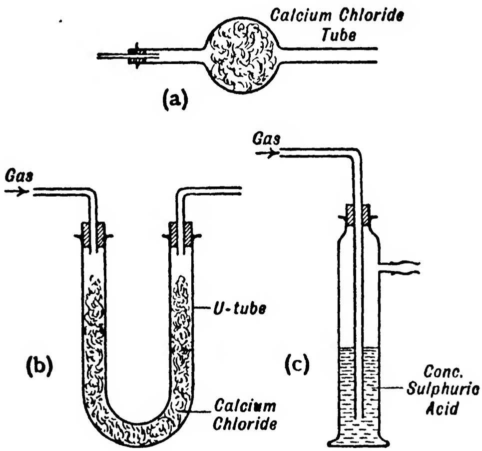



FIG. 8.—Drying vessels

Solids which absorb moisture from the air to such an extent that they dissolve in it and ultimately form a clear solution are said to be **deliquescent.**

Liquids which absorb moisture rapidly are said to be **hygroscopic.**

Crystalline bodies which lose their water of crystallisation and become coated with an opaque powder are said to be **efflorescent.**

Deliquescent and hygroscopic bodies which absorb moisture

rapidly are used for drying gases or solids. Gases are usually dried by being passed through the deliquescent (or hygroscopic) substance contained in vessels such as are shown in fig. 8 (*a*), (*b*), (*c*).

Sometimes small pieces of glass rod, or pieces of pumice, are put into a U-tube and coated with concentrated sulphuric acid to provide a drying tube.

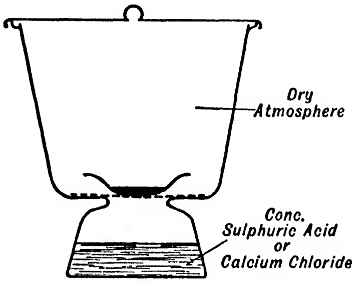



FIG. 9.—A desiccator

To dry solids in the form of powders a piece of apparatus known as a **desiccator** is used (fig. 9). Some desiccators are fitted with a tap in the lid so that they may be partially vacuated. This causes the moist powder to give up its moisture more readily to the drying agent. Calcium Chloride, Phosphorus Pentoxide, Quicklime, concentrated Sulphuric Acid are all drying agents, and you will constantly meet them in your chemistry course.

## QUESTIONS

1. Explain the terms "efflorescence" and "deliquescence." How would you demonstrate which property is possessed by (*a*) washing soda, (*b*) Calcium Chloride?
2. Draw diagrams of pieces of apparatus which can be used for drying (*a*) gases, (*b*) solids and liquids.

## CHAPTER II

## ELEMENTS, MIXTURES, COMPOUNDS. HYDROGEN AND WATER

In olden times Air was regarded as one of four "elements," Earth, Air, Fire, and Water. These four "elements" really stood for qualities, *e.g.* Fire represented the qualities of hotness and dryness; Water, coldness and wetness; Air, hotness and wetness; Earth, coldness and dryness. This is quite different from our present idea of an element. The name **element** is now used for a substance which cannot by ordinary chemical processes be split up into two or more distinct substances. Thus Iron, Copper, Lead, Sulphur, Oxygen, Nitrogen, Hydrogen are elements. There are some 89 of them known at present, and from them are built up the thousands of compounds at our disposal.

When elements or other chemical substances are put together and there is no evidence of any chemical change, no heat given out or absorbed, no light, no visible action of any sort, the resulting substance is said to be a **mixture.**

Examine the element iron—note its attraction by a magnet, note its colour; its relative density you have already determined to be 7·7.

Now examine some flowers of sulphur. *Is this element attracted by a magnet?* Its colour distinguishes it easily from iron. It can be dissolved in a liquid, Carbon Disulphide. Its relative density is approximately 2·0.

Iron and sulphur are two elements possessing their own distinctive properties. If iron filings and sulphur be thoroughly mixed together in the proportions of 7 parts by weight of iron and 4 parts by weight of sulphur it is observed that the colour is somewhere between the grey of iron and the yellow of sulphur, its relative density is between 7·7 and 2·0, but nearer 7·7. *Why is this?* Examine the mixture under a microscope. The particles of iron and the particles of sulphur are clearly

visible. Apply a magnet to the mixture. *Which is attracted, the iron or the sulphur ?*

**Demonstration**—Shake up a small quantity of the mixture with a little Carbon Disulphide,[1] and filter into a watch-glass, using a dry filter-paper. The liquid evaporates, leaving crystals of sulphur in the watch-glass. The iron remains on the filter-paper. There has been no combination of the iron and the sulphur—this is called a **mixture.** The iron and sulphur were simply **mixed** together, and could be separated without chemical action. Now heat together in a test-tube the mixture of 7 parts by weight of iron and 4 parts by weight of sulphur. As soon as a red glow appears in the tube remove the Bunsen flame. *Does the glow cease or does it travel throughout the whole of the mixture ?* Examine the residue in the tube. Apply a magnet. *Can any iron be extracted ?* Shake up with a little Carbon Disulphide and proceed as before. *Can any Sulphur be dissolved by the Carbon Disulphide ?*

The iron and the sulphur are no longer present as separate elements. They have combined together to form a **chemical compound.** No doubt you noticed that much heat was given out from the moment the iron and sulphur started to combine. It is a curious fact that it is only the proportion of 7 parts by weight of iron and 4 parts by weight of sulphur that will enter into chemical combination in this way. They can be **mixed** together in any proportion, but nothing will induce the 7 parts of iron to take more than 4 parts of sulphur in this experiment, and if excess of either is used it will be left uncombined at the end. **Elements which combine, always do so in some fixed proportion by weight.** This is one of the fundamental laws of chemical combination which will be dealt with later. Mixtures do not obey this law of fixed composition. It is very difficult to split up a chemical compound once it has been formed, and the elements composing it completely lose their own individual properties. The harmless common salt is composed of two elements Sodium and Chlorine, either of which would kill you if taken separately in quantities

[1] Carbon Disulphide is highly inflammable and should be kept away from a flame.

approaching the amount eaten when the two are chemically combined. Thus a very important fact for you to remember is that **although a compound is composed of certain elements, these elements do not possess any of their individual properties.**

## Water and Hydrogen

Water was in the list of so-called "elements" given at the beginning of this chapter. By this was meant that it represented the qualities of wetness and coldness. We are going to examine water to find out if it is a single substance which cannot be split up or if it is composed of more than one chemical element.

Examine the metal Sodium. Note that it can be cut easily with a knife and that the freshly-cut surface is of silvery appearance, but very soon tarnishes when exposed to the air. **Sodium must be treated with very great care if there is any water about, as it reacts very violently with water and dangerous accidents may occur.**

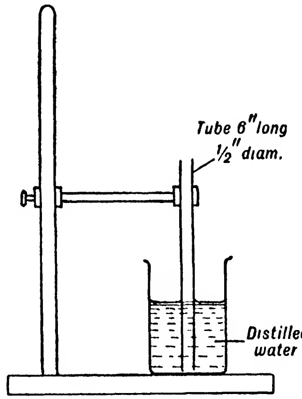



Fig. 10.

Fit up an apparatus shown in fig. 10. Drop pieces of Sodium about the size of a lead shot down the tube. (Wait until one piece has disappeared before adding another.) Apply a light to the top of the tube. The gas, which takes fire with a "pop," is called **Hydrogen.** The Sodium disappears. *Can you suggest where it has gone?* When common salt dissolves in water the salt can be recovered by evaporating to dryness. Try to recover the Sodium in the same way. Evaporate about one-half of the solution.[1] Describe the residue you get on evaporation. Compare this residue with the metal Sodium—obviously it is *not* the metal.

[1] If a nickel crucible is available it is wiser to use it, as the molten residue is not good for porcelain glaze.

*Where do you think the gas which exploded came from?* Perhaps this gas was dissolved in the water and can be driven out by boiling. Using the apparatus shown in fig. 11, try to collect any gas given off when the water is heated. If some gas collects, close the end of the test-tube by means of the thumb, invert it, remove the thumb and apply a light. *Does the gas ignite? Can it be Hydrogen?* Any gas which collected was probably air which was dissolved in the water. The Hydrogen given off when Sodium acted on water must have come from the water, and yet water does not contain Hydrogen **dissolved** in it.

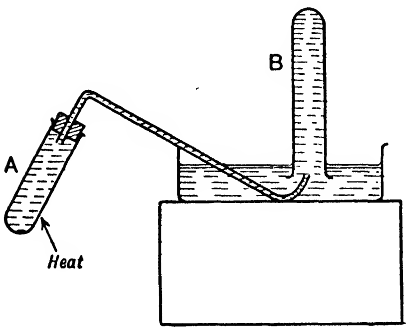


FIG. 11.

Now feel the "Water" left in the beaker in which the Sodium has disappeared. It feels slimy to the fingers. Add some of the vegetable dye litmus, and note what happens. Substances which turn litmus blue are called **alkalis.**

From the observations made it is clear that Sodium acts in some way upon water, drives out Hydrogen gas, and leaves an alkaline solution behind. Such action is called **chemical action.** The reaction of Sodium and water may be expressed as follows:

$$\text{Sodium} + \text{water} \rightarrow \text{Hydrogen} + \text{an alkali.}$$

The alkali in this case is called **Caustic Soda,** or **Sodium Hydroxide.**

## The Preparation of Hydrogen

A few pieces of metallic Calcium in the form of turnings or borings are placed at the bottom of the test-tube (A), in an apparatus similar to fig. 11, and a little distilled water added. Immediately an action takes place, which is not so violent as in the case of Sodium, but it is obvious that a gas is being given off. Collect this gas in a test-tube which has previously been

filled with water and inverted over the end of the delivery tube as shown at B, fig. 11. When the tube B is full of the gas close the end with the thumb, remove as in last experiment and apply a light to the mouth of the tube. *What is this gas?* Filter the liquid left in the test-tube. Divide the filtrate into two portions (i) and (ii). To (i) add litmus and *note the effect.* Breathe into (ii) through a glass tube and note what happens. *Have you previously used any liquid that behaves in a similar manner?* Calcium decomposes water, giving Hydrogen gas and an alkali. The alkali in this case is lime-water, which is a solution of **Calcium Hydroxide** in water.

Calcium + water → Hydrogen + Calcium Hydroxide.

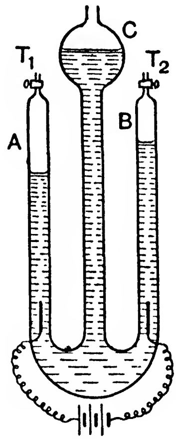


Fig. 12.—Apparatus for decomposing water by electric current

**Demonstration**

**Splitting up Water by Electric Current**—The apparatus shown in fig. 12 is used and an electric current from 2 or 3 accumulators is passed through the water.[1] In a short time gases are seen to collect in the tubes A and B, and there is twice as much gas in one tube A as there is in the other. When sufficient gas has collected in A and B, place a test-tube over the exit tube of A. The water in the reservoir C must be at a level above the exits of the tubes A and B. *Why is this?* Carefully open the tap $T_1$ and collect the gas in the test-tube. Remove the test-tube and try to light the gas contained in it. *What do you think the gas is?* Now collect some of the gas from the tube B—plunge a glowing chip of wood into the mouth of the test-tube. *What happens? What are the two gases into which water has been split up? What are the proportions by volume of these gases?* All these experiments show that water is not an element but a compound.

Using the apparatus shown in fig. 13, Cavendish in 1781

[1] A little Phosphorus Pentoxide is dissolved in the water in order to make it conduct the electric current more readily.

set fire to a mixture of common air and Hydrogen (which he called inflammable air) by means of a spark. In describing the result of the experiment he says: "Almost all the inflammable air and about one-fifth of the common air lose their elasticity (gaseous form) and are condensed into the dew which lines the glass." There was no change in weight after the explosion. By this experiment Cavendish found that two volumes of Hydrogen combine with one volume of Oxygen to form water.

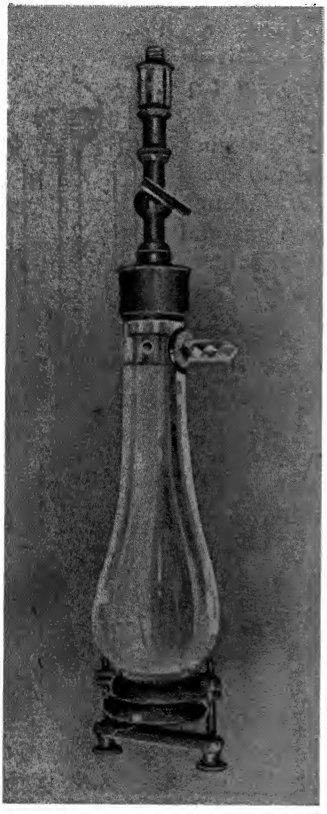


FIG. 13. — Cavendish's firing globe (Reproduced from Partington's *Composition of Water*, Bell)

You will now perform an experiment which will enable you to examine the nature of the "dew" talked about by Cavendish.

Some Calcium turnings are placed in a strong glass bottle fitted up as shown in fig. 14. Water is poured down the thistle funnel and Hydrogen gas is immediately formed. It will be necessary to have a can containing cold water surrounding the bottle to prevent the action becoming too vigorous. The Hydrogen is passed through a U-tube containing Calcium Chloride, which absorbs moisture and so dries the gas, which passes out through the tube A. **Before applying a light to A it is very important to collect a test-tube full of the gas. If, when a light is applied to the mouth of the test-tube, a loud report is heard, it will be dangerous to apply a light to A.** It takes some little time for the Hydrogen to drive out all the

air from the apparatus, and a mixture of Hydrogen and air explodes violently. Several trials should be made until the test-tube full of Hydrogen explodes **very quietly.** It will then be safe to apply a light to the nozzle A. Before doing so allow the Hydrogen gas to play on the under surface of the flask. *Is any water deposited? Would you say the Hydrogen gas was dry?* Now apply a light and allow the Hydrogen flame to play on the surface of the flask, which is kept cool by

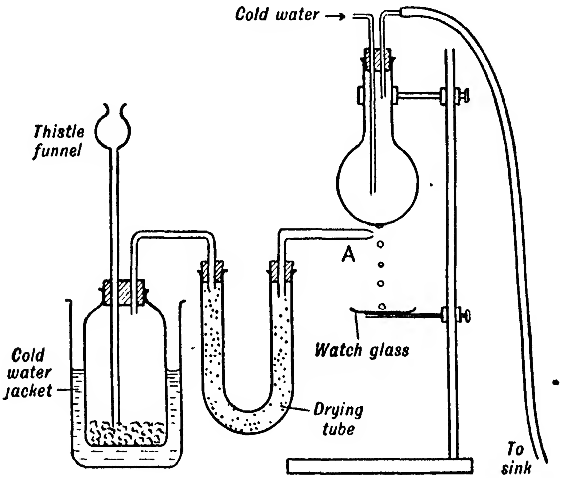



FIG. 14.—Apparatus for forming water by burning Hydrogen

water circulating through it. The watch-glass is arranged below this flask to collect the " dew " formed.

When this experiment has been progressing for some little time there should be sufficient liquid in the watch-glass for examination. First try the effect of a few drops on anhydrous Copper Sulphate. If several groups of pupils have performed the experiment there should be sufficient liquid to collect in a test-tube and find the boiling-point. The freezing-point could also be found. These two temperatures will indicate that the " dew " is none other than pure water.

## Another Example of the Analysis of Water

If water in the form of steam is passed over iron nails contained in a heated tube the iron takes Oxygen from the steam and Hydrogen is set free.

The above experiment may be done as a demonstration, using apparatus shown in fig. 15, and the gas collected in the gas jar tested with a lighted taper. The " iron " nails should

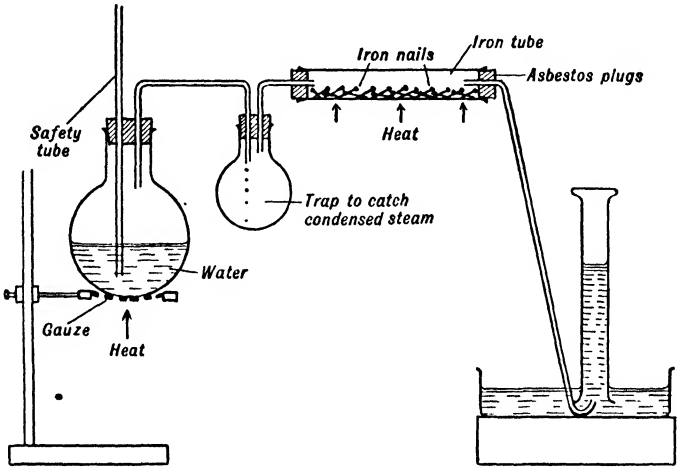



Fig. 15.—Analysis of water by passing steam over red-hot iron

be shaken out of the tube and examined to see if any difference can be noted.

The iron has now been **oxidised** by the Oxygen taken out of the steam.

$$\text{Iron} + \text{Steam} \rightarrow \text{Iron oxide} + \text{Hydrogen}.$$

A striking modification of this experiment is the decomposition of steam by Magnesium contained in a heated silica tube.

Compare the residues left in the tubes with the oxides formed when Iron and Magnesium were burnt in Oxygen.

## Reverse the above Reaction

Make Hydrogen by the action of Calcium on water. Dry it by passing through concentrated Sulphuric Acid or Calcium

Chloride and pass over heated magnetic Oxide of Iron contained in a combustion tube (fig. 16). Be careful to test the Hydrogen escaping from the exit tube before heating the combustion tube.

*Is there any sign of moisture being deposited in the tube* A *or in the combustion tube between* A *and the boat? Is there any sign of moisture beyond the boat?* Test the liquid with anhydrous Copper Sulphate. *Was the water present in the Hydrogen*

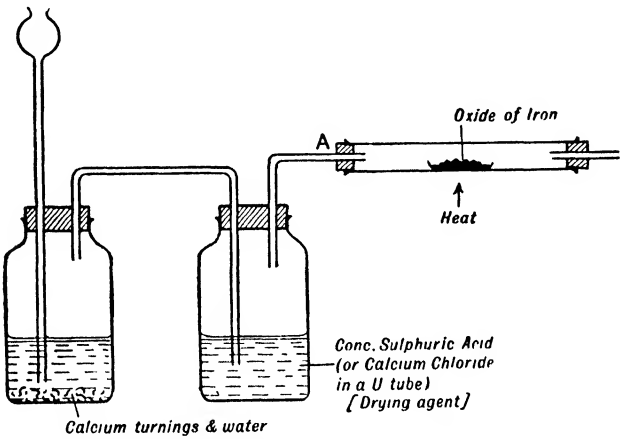



FIG. 16.—Passing dry Hydrogen over Oxide of Iron

*passed into the tube?* Write an " equation " expressing what has taken place. Compare your equation with

$$\text{Iron} + \text{Steam} \rightarrow \text{Iron Oxide} + \text{Hydrogen}$$

Suppose it were possible to do this chemical experiment in a closed flask, *what would you expect to happen?* Such a chemical reaction is called a " **reversible** " **reaction.** Both the above reactions are possible because in the first case the current of steam swept out the Hydrogen and therefore it could not act upon the Iron Oxide formed. In the second case the current of Hydrogen swept out the steam and so removed it from contact with the hot Iron, thus preventing any action between them. If, however, the reaction took place in a

closed vessel we should expect to find Iron, Steam, Iron Oxide, and Hydrogen all present. The reaction between steam and Magnesium is not reversible. Hydrogen will not react with Magnesium Oxide.

You will meet many other cases of reversible reactions in the course of your study of chemistry

## QUESTIONS

1. How would you determine the percentage composition of the following mixtures: (*a*) chalk and salt, (*b*) lime and sand ?
2. Some common salt, sawdust, and distilled water are shaken together in a bottle. Describe how you would obtain each one free from the other two with as little loss as possible. Give a drawing of the apparatus used.
3. Gunpowder consists of Carbon, Nitre, and Sulphur. How would you proceed to obtain a pure specimen of Nitre and Sulphur ?
4. What are the principal differences between compounds and mixtures of the same substances ?
5. How may Hydrogen be obtained from water ? What are the principal properties of the gas ?
6. Describe an experiment to show that when Hydrogen burns in air water is formed. (You must give proof that the liquid obtained *is* water.)
7. Give an example of a "reversible" reaction, and describe experiments to show that the reaction you choose is reversible.

## CHAPTER III

## THE COMMON MINERAL ACIDS. PREPARATION OF SALTS

A MINERAL is a non-living substance found in the earth or on the surface of the earth. The acids which you are now going to study are in some way or other made by using **minerals.**

Occasionally in a piece of coal you see a hard brassy-looking substance which " shoots " out of the fire when the coal is burnt. This substance is a compound of Iron and Sulphur, and is called iron pyrites. It is found quite commonly in iron ore. The word pyrites in Greek means " flint," and pyr means " fire." It is quite possible that this hard substance was used to strike flint and obtain a spark which primitive peoples used to light " tinder " preparatory to making a fire.[1] If this iron pyrites is placed under a shed for some months and exposed to damp air, but protected from rains, it slowly changes and becomes coated with a greenish powder. This powder dissolves in water, and from the solution crystals can be obtained which look very much like bits of green glass. Long ago man discovered these green crystals and called them green vitriol (Lat. vitreus = of glass). The modern name for these crystals is Ferrous Sulphate.

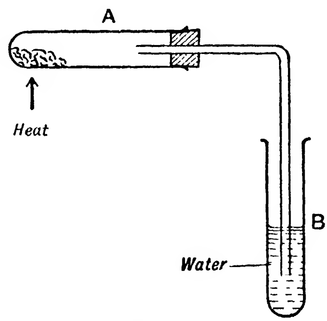


FIG. 17.

### Experiment 1

Place a few crystals of Green Vitriol in a test-tube fitted up as shown in fig. 17. Heat the crystals very gently at first and then strongly. Note all the changes you can in the

[1] Iron pyrites and tinder-boxes have been found among human remains in caves.

appearance of the crystals. At the end of the experiment test the liquid in the test-tube B with litmus to find out if it is acid or alkaline. The crystals change in colour from green to white and eventually to red. The first change is due to water of crystallisation being given off (*cf.* with Copper Sulphate crystals mentioned in Part I, page 22).

Green Vitriol Crystals →White anhydrous Ferrous Sulphate + water.
(Ferrous Sulphate Crystals)

The second change from white to red may be represented as follows :—

$$\text{White anhydrous Ferrous Sulphate} \rightarrow \underset{\substack{\text{(Iron Oxide)} \\ \text{(Ferric Oxide)}}}{\text{Jeweller's rouge}} + \underbrace{\text{oil of vitriol.}}_{\text{an acid}}$$

The modern name for oil of vitriol is **Sulphuric Acid.** From its origin you can see why it is called a mineral acid.

**Experiment 2**

**To observe the effect of Oil of Vitriol on** (*a*) **Common Salt,** (*b*) **Nitre or Saltpetre**—You have already learned that common salt is a mineral. Saltpetre is also a mineral, its name "Sal petræ" means "Salt of the rock," and it was so called because it was found on the surface of the soil in the neighbourhood of Indian villages after the rainy season had ended and the hot season had begun. Its origin can be traced to the decomposition of animal products in the soil of a country where our modern drainage and sewage systems are unknown. Its chemical name is Potassium Nitrate.

No doubt you have noticed a fluffy efflorescence on the walls of buildings such as stables or cellars of inhabited houses. This is another nitrate, lime-saltpetre or Calcium Nitrate. This substance was used during the French Revolution as a source of nitre which the revolutionists used in the manufacture of gunpowder (a mixture of Nitre, Sulphur, and Carbon).

These two minerals, salt and nitre, when acted upon by oil of vitriol yield two other mineral acids.

Add a little concentrated Sulphuric Acid (oil of vitriol) to about a teaspoonful of common salt in a test-tube. *What*

*happens?* Owing to the difficulty of "catching" a gas which seemed so easily to vanish into the air the early chemists called all gases **spirits,** and this gas for many years was called "Spirit of Salt." Let us try to catch this "spirit" and hold it in solution in water.

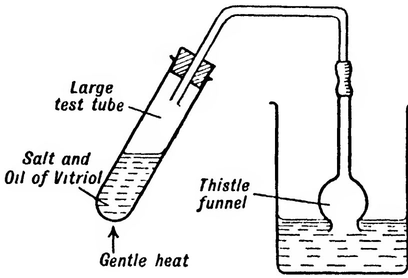


FIG. 18.

Fit up the apparatus shown in fig. 18, arranging the thistle funnel (why is it called a *thistle* funnel?) so that it is just below the surface of the water. Observe the thistle funnel carefully and try to suggest why it is used. Keep the solution formed for examination later.

Now try the effect of oil of vitriol on nitre. *Is the action so vigorous as in the case of salt?* Heat the test-tube gently and describe the appearance of any gas given off This was originally called "Spirit of Nitre."

If you examine the cooler part of the test-tube you will find that this gas condenses on the sides of the tube.

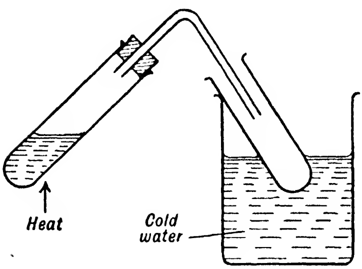


FIG. 19.—Apparatus for acting on Nitre with Oil of Vitriol

Now fit up the apparatus shown in fig. 19 and try to condense some of the gas given off.

The **solution** of the "Spirit of Salt" in water is now called Hydrochloric Acid, a name given to it by Davy in 1810.

The **condensed** "Spirit of Nitre" is called Nitric Acid. It was first prepared in this way by Glauber in 1650, and for long afterwards was called *spiritus nitri fumans Glauberi.* It was probably first called Nitric Acid in the time of Lavoisier and Cavendish, *c.* 1784.

**Experiment 3**

**To discover the simpler Properties of the common Mineral Acids**—The properties of the concentrated acids will be demonstrated by the teacher, because they are a little dangerous for you to use at this stage. You should tabulate the observations as follows :—

**Concentrated Sulphuric Acid**

(i) Appearance.

(ii) Relative Density.

(iii) Effect on paper, wood, cork.

(iv) Effect when poured into water. Note the rise in temperature when 25 c.c. of concentrated Sulphuric Acid are added *a little at a time* to 50 c.c. of water. *N.B.*—**Never add water to concentrated Sulphuric Acid;** always pour the acid into the water.

| | |
|---|---|
| (v) Effect on (*a*) Iron<br>(*b*) Zinc<br>(*c*) Tin<br>(*d*) Copper<br>(*e*) Magnesium | Describe as fully as you can all that happens. Try cold acid first, and, if no action is observed, heat (but do not boil). |

**Concentrated Nitric Acid**—Proceed as for concentrated Sulphuric Acid. Under heading (iv) state whether you consider it to be dangerous to add concentrated Nitric Acid to water.

**Concentrated Hydrochloric Acid**—Proceed as for concentrated Nitric Acid.

**Dilute Sulphuric Acid**—(i) Try the effect of the dilute acid on paper, wood, cork. *Is it so destructive and corrosive as the concentrated acid ?*

(ii) *What is the effect on litmus solution ?*

(iii) Try the effect of the dilute acid on (*a*) Iron, (*b*) Zinc, (*c*) Tin, (*d*) Copper, (*e*) Magnesium. Apply a light to the mouth of the test-tube if any gas seems to be evolved.

In the case of (*a*), (*b*), (*e*) add sufficient metal to act on all the acid when warmed gently; filter, and set aside to cool. Describe any crystals you obtain.

*N.B.*—This may be done as a co-operative experiment, some members of the class doing the experiment with Iron, some with Zinc, etc., and the results compared by all members of the class.

Repeat the above experiments with **dilute Hydrochloric Acid** and with **dilute Nitric Acid.** All the results should be tabulated and the principal differences in the behaviour of the three acids noted.

The crystalline substances which you have obtained are called **salts.** The three common acids and their corresponding salts are tabulated below:

| **Acid** used— | **Salt** formed— |
|---|---|
| Sulphuric | A sulphate |
| Hydrochloric | A chloride |
| Nitric | A nitrate |

The particular metal used gives its name to the sulphate, chloride, or nitrate as the case may be. For example, we have Zinc Sulphate, Ferrous (Iron) Sulphate, Magnesium Chloride, Copper Nitrate, etc.

## Oxides, Acids, and Bases

**Other Methods of Preparation of Salts**—When Carbon, Phosphorus, and Sulphur were burnt in Oxygen the resulting oxides when dissolved in water turned litmus red. These oxides are said to be **acidic.** It was on this account that Lavoisier named the gas **Oxygen**—a name which means **acid-producer.**

If, however, Magnesium and Sodium are burnt in Oxygen and the resulting oxides dissolved in water it is found that the solutions turn litmus blue. Hence the term "Oxygen" is really a misnomer, but it has been retained for the gas.

Acidic oxides are usually oxides of non-metals. Oxides of metals are called Basic Oxides.

Acidic oxides and basic oxides will neutralise one another in presence of water and form a class of bodies known as **salts.**

You remember forming a salt in this way when you acted on lime-water with Carbon Dioxide. Lime-water is a solution

in water of the oxide of the metal Calcium. It is a solution of a basic oxide in water. Carbon Dioxide is an acidic oxide. The salt formed by the interaction of the two substances is called Calcium Carbonate.

**The Preparation of Salts**—In the experiments which you will perform on the formation of salts you will often use the hydroxide instead of the oxide of the metal. The hydroxide is formed when a soluble basic oxide is dissolved in water, and is a chemical base.

(*a*) **By Neutralisation of a Basic Oxide with an Acid—Preparation of Copper Sulphate Crystals**—Pour about 50 c.c. of water into an evaporating basin, and add about 10 c.c. of concentrated Sulphuric Acid. Put the evaporating basin on a tripod and heat. Add Copper Oxide, a little at a time, until no more will dissolve. Filter while the liquid is still hot, and collect the filtrate in a clean evaporating basin. Take out a drop of the liquid on the end of a glass rod and note whether or not crystals form in the drop on cooling. If they do, the solution may be allowed to cool; if not, concentrate the solution until crystallisation will occur on cooling. Pour off the liquid above the crystals, wash with a little *cold* water, and finally dry between filter-papers. Describe the Copper Sulphate crystals, and if you have a large enough crystal draw it to show its shape. Hang one of these small crystals, which is as perfect in shape as you can get, in a beaker (or jam jar) containing a saturated solution of Copper Sulphate, and try to "grow" it (fig. 20).

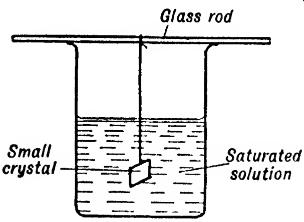


FIG. 20.—"Growing" a large crystal

(*b*) **By Neutralisation of a Hydroxide with an Acid**—This method will be used for the preparation of the salts Sodium Chloride and Potassium Nitrate.

(i) **Preparation of Sodium Chloride**—Take a piece about 1 in. long of a stick of Caustic Soda (Sodium Hydroxide). Put it into an evaporating dish and examine it. Note the

feel of it and also any change in its appearance as it stands in the air.

Dissolve it in a little over 50 c.c. of distilled water. Pour the solution into a burette. Into another burette pour dilute Hydrochloric Acid. Wash the evaporating basin and run into it 25 c.c. of the Sodium Hydroxide solution. Add a few drops of litmus solution.

Note the level of the Hydrochloric Acid in the burette and run the acid into the base until the litmus just changes colour. Stir after each addition of acid. Note the volume of the acid used.

You now know how many c.c. of the acid solution are required to neutralise 25 c.c. of the Caustic Soda solution. Into a clean evaporating basin run 25 c.c. of the Caustic Soda solution and add the correct amount of the Hydrochloric Acid, this time omitting the litmus. Concentrate to crystallising point ; cool by allowing the basin to stand on a beaker full of cold water and dry the crystals between filter-papers. *Why do you think it was necessary to divide this experiment into two parts ?* (Find out if litmus affects the colour of the crystals by allowing a little of the solution containing litmus to crystallise.)

(ii) **Preparation of Potassium Nitrate**—Examine a little Caustic Potash (Potassium Hydroxide). Proceed in this experiment exactly as in the last, except that the burettes will contain Potassium Hydroxide solution and dilute Nitric Acid in place of Sodium Hydroxide solution and dilute Hydrochloric Acid.

## Definitions

**Base**—The oxide or hydroxide of a metal, which, if soluble in water, will turn neutral litmus blue and which will neutralise an acid to form a salt and water only.

**Acid**—A body containing Hydrogen which can be replaced wholly or in part by a metal. It will turn neutral litmus red and will neutralise a base forming a salt and water only.

**Salt**—The result of the interaction of acids and bases, or the replacement of the hydrogen of an acid by a metal.

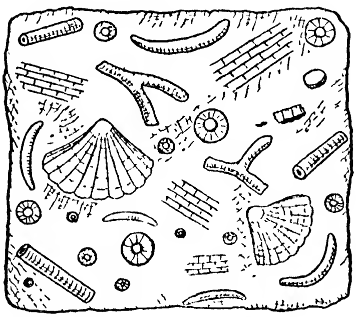
## QUESTIONS

1. What is the meaning of the word Pyrites? Why do you think the mineral Iron Pyrites was so called?
2. Describe fully the action of heat on Ferrous Sulphate Crystals and on Copper Sulphate Crystals.
3. Describe the preparation of a strong solution of Hydrochloric Acid. Draw and explain the apparatus used.
4. What action has dilute Hydrochloric Acid on (*a*) Iron, (*b*) Magnesium, (*c*) Copper?
5. What happens when concentrated Sulphuric Acid is (*a*) poured into cold water, (*b*) poured on paper, (*c*) warmed with Copper, (*d*) used in a desiccator?
6. How would you prepare and collect a sample of Nitric Acid? Describe its appearance. What action has it on Tin and Copper?
7. Explain the terms basic oxide, acidic oxide. Give two examples of each.
8. Describe, with all experimental details, the preparation of pure dry crystals of Copper Sulphate, starting with Copper Oxide.
9. How would you prepare pure dry crystals of Potassium Nitrate starting from Caustic Potash?

## CHAPTER IV

## CHALK, QUICKLIME, LIME-WATER. HARD AND SOFT WATERS

CHALK is composed almost entirely of shells and the bone remains of minute sea organisms. About 5,000,000 tons are quarried annually in England, and much is exported to



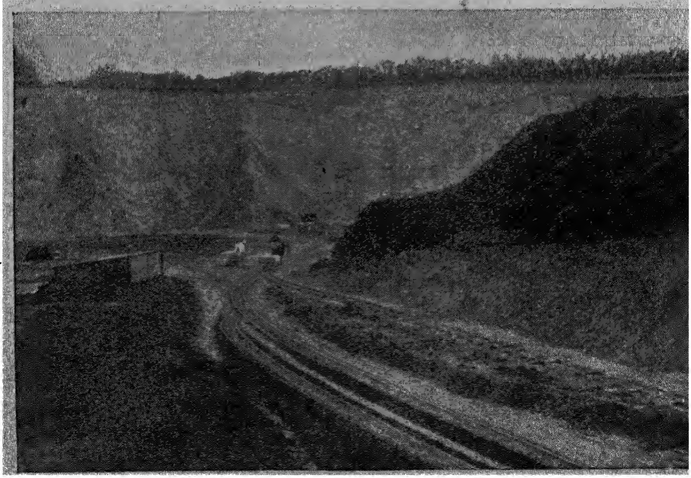
Typical shells found in a piece of chalk

the United States of America. The chief chalk deposits in England are the North and South Downs, the Chilterns, and the Cotswolds. These deposits show that at one time much of this country was under the sea.

### Experiment 1

**To find out what happens when Chalk is burnt**—For this experiment a midget furnace (fig. 21) will be found very useful. It consists of two cylinders of fireclay on a circular stand, arranged so that they can enclose the flame of a large Bunsen burner. A triangle (fig. 22) is made by twisting together three iron wires as shown (ordinary galvanised wire about $\frac{1}{10}$ in. diameter will serve quite well). This triangle holds a porcelain crucible and is supported between the two cylinders. It has

Chalk escarpment at Totternhoe, near Dunstable



Working a chalk deposit

*(By courtesy of Totternhoe Lime and Stone Co., Ltd.)*

been found that the china clay rings from old gas-mantles can be used effectively to hold the crucibles during heating. Weigh a piece of natural chalk [1] in a weighed crucible and find the loss in weight after heating for several hours. The following weighings were obtained as the result of such an experiment. Your results should be entered in a similar manner.

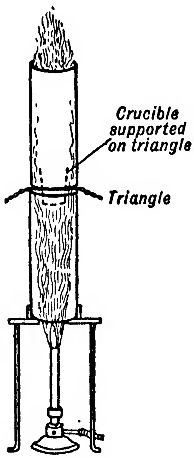


FIG. 21.

| | |
|---|---|
| Weight of crucible . . . | 8·07 grm. |
| ,, ,, ,, + chalk . | 9·14 grm. |
| ∴ weight of chalk . . . | 1·07 grm. |
| Weight of crucible + residue after heating . . . . | 8·67 grm. |
| Loss in weight . . . | 0·47 grm. |

% loss in weight $= \frac{\cdot 47}{1\cdot 07} \times 100 = 43\cdot 9\ \%$.

**Experiment 2**

**Examination of the Residue left after heating Chalk**—There seems little change in appearance, but it is known that there has been a loss in weight.

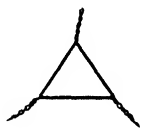


FIG. 22.

(*a*) Let a few drops of water drip on a piece of chalk and repeat with the residue left after heating. Make a careful record of all you observe (see illustration below).

Action of water on quicklime

(*a*) Water poured on (*b*) Lump emits steam and swells (*c*) Final result—dry soft slaked lime

(*b*) Make a paste of the residue by adding more water. Put a piece of red litmus paper in the paste and note the effect.

[1] Do not use blackboard "chalk."

Do you get the same result when powdered chalk is mixed with water and litmus paper introduced ?

(*c*) Add still more water, stir well and filter. Breathe into the liquid and note what happens. The liquid is **lime-water,** and the residue formed when chalk is heated is **quicklime.**

**Experiment 3**

**To test the Gas given off on heating Chalk**—Powder some chalk and heat strongly in a small test-tube fitted with a cork and delivery tube (see fig. 23). Pass the gas evolved into lime-water and note the effect.

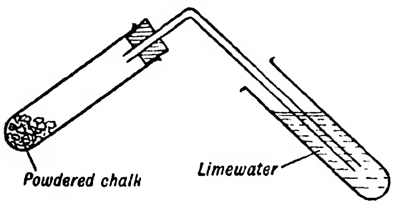



FIG. 23.

The results of the above experiments may be summed up as follows :

Chalk is a neutral salt. Its chemical name is **Calcium Carbonate.** On being heated it gives off 44 per cent. of its weight as **Carbon Dioxide** and a residue of quicklime is left. The chemical name for quicklime is **Calcium Oxide.**

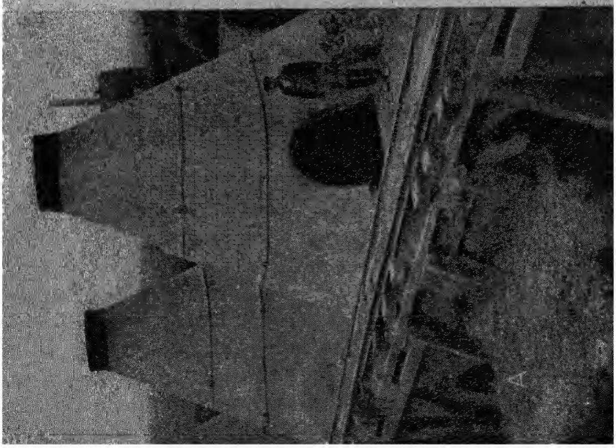
The reaction on heating chalk may be represented as follows :

$$\underset{\text{(Calcium Carbonate)}}{\text{Chalk}} \rightarrow \underset{\text{(Calcium Oxide)}}{\text{Quicklime}} + \text{Carbon Dioxide} \uparrow$$

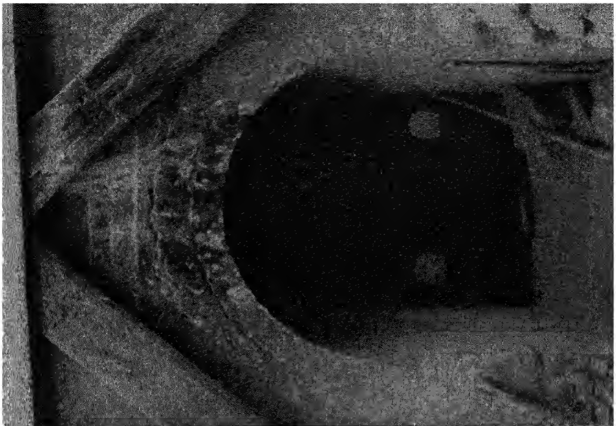
Quicklime (Calcium Oxide) on being treated with water gives out much heat, so much that some of the water is converted into steam. In this process the quicklime crumbles ; some of the water has combined with the quicklime, forming a new compound, **slaked lime (Calcium Hydroxide). This** new substance is only slightly soluble in water. If stirred with water it gives a milky-looking mixture, which is called **milk of lime,** and is used in its pasty form by the builder for making mortar.

$$\text{Calcium Oxide} + \text{water} \rightarrow \text{Calcium Hydroxide.}$$

The clear solution of calcium hydroxide obtained after filtering milk of lime is called **lime-water.**



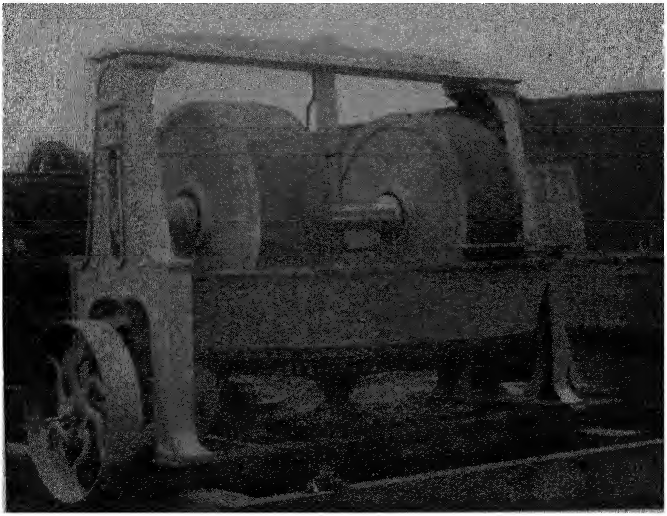
Lime kilns



Interior seen through A

*(By courtesy of Totternhoe Lime and Stone Co., Ltd.)*

Chalk burning is an important industry, as lime is used not only for making mortar but as an ingredient for certain cements. It is also used for agricultural purposes. The illustration shows a modern limekiln in operation. The chalk, which is mixed with coal, is fed in at the top of the kiln and is " fired " or burnt. The quicklime, which is mixed with a certain amount of ash from the coal, is raked out at the bottom.



A mortar mill
*(By courtesy of Messrs. Lewis & Lewis)*

The presence of ash is of no detriment for quicklime that is going to be used by builders or cement makers. The easiest way to make mortar is to mix sand with the pasty form of slaked lime referred to above. In districts where sand is dear, mortar is made by grinding ashes (cinders) with the slaked lime in a mill about 8 feet diameter, shown in the above illustration. It is owing to the fact that slaked lime can take in Carbon Dioxide from the air and become Calcium Carbonate that mortar gradually hardens and binds bricks together Test a little old mortar for the presence of a carbonate afte you have performed Experiment 5 (i) (p. 34).

**Experiment 4**

**To test the effect of** (*a*) **Pure Water,** (*b*) **Rain Water on a layer of Chalk**—Two tubes about 4 ft. long and 1 in. diameter are fitted up as shown in fig. 24. A piece of muslin is tied round the bottom end of the tube and the first half inch filled with fine sand. The rest of the tube is filled with natural chalk broken into pieces about the size of small peas. Each sample of water is run through the tubes several times and allowed to drip slowly into the bottle below.

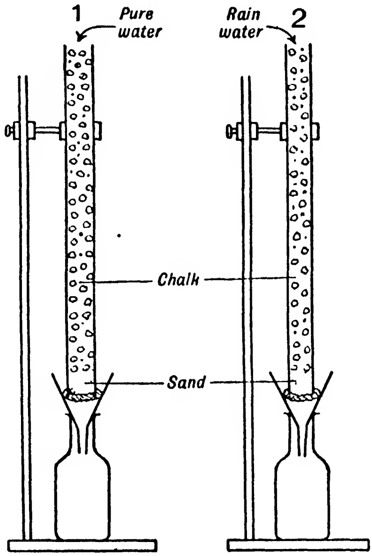



FIG. 24.—Apparatus to test the effect of water on chalk

**Examination of the Samples of "Water" obtained as above**—(i) A solution of pure Castile soap is made in alcohol and distilled water.[1] Pour some of the soap solution into a burette. Pour 25 c.c. of "water" from tube 1 into a bottle, and 25 c.c. of "water" from tube 2 into another bottle. Allow the soap solution to run into each bottle in turn drop by drop and shake well after each addition. Note the volume of soap solution which must be added in each case to produce a **lather** which does not become a curdy precipitate almost immediately.

(ii) Evaporate to dryness in a clean dish 100–200 c.c. of a fresh sample of each water. *Is chalk soluble in distilled water? Has chalk been dissolved by the rain-water?* Rain-water as it passes through the air dissolves some Carbon Dioxide. Before rain-water reaches the chalk rock, which is at varying distances below the surface of the soil and vegetation, it

[1] 5 grm. of soap dissolved in 50 to 100 c.c. warm water + 10 c.c. alcohol and finally made up to a litre.

dissolves more Carbon Dioxide from the upper layers of soil. These always contain some Carbon Dioxide which is given off from all green vegetation. This fact you will test experimentally later in your course of study. By the time it reaches the chalk rock, therefore, the rain-water has dissolved a considerable quantity of Carbon Dioxide. It will therefore be clear that drinking-water which is pumped from wells below the chalk rock will not form an immediate lather with soap. Such water is called **hard water.**

**Experiment 5**

**A Test for Carbonates**—Treat a little chalk with dilute Hydrochloric Acid, with dilute Nitric Acid, with dilute Sulphuric Acid, and in each case pass the gas evolved into lime-water. Treat any other carbonate in the same way. **All carbonates give off Carbon Dioxide when treated with dilute acids.** Of these acids Hydrochloric is the best to use. This gives you a test for carbonates.

**Temporary and permanent Hardness of Water and their removal**—(i) Pour some of the clear water obtained from tube 2 in Experiment 4 into a test-tube. Fit the test-tube with a cork and delivery tube the end of which dips into lime-water contained in another test-tube. Boil the solution and note if any sediment is formed in the test-tube and whether the lime-water is affected. *If a sediment is formed in the test-tube, what test can you apply to find out if it is a carbonate?* You should be able to show that the white sediment is a carbonate, and it is obvious that it can only be Calcium Carbonate. Calcium Carbonate is insoluble in water, and therefore when the Carbon Dioxide acts upon it a new substance must be formed, which is soluble in water. This new substance is called **Calcium Bicarbonate.** On boiling a solution of Calcium Bicarbonate, Carbon Dioxide is evolved and Calcium Carbonate is precipitated. Therefore by boiling and subsequent filtering one can get rid of Calcium Bicarbonate which is in solution in water.

Water containing the Bicarbonate of Calcium (or Magnesium) is called **hard water,** because it does not give an immediate lather with soap, as you have found from Experiment 4.

(ii) **To get rid of the hardness due to Calcium Bicarbonate**—Boil a sample of water containing Calcium Bicarbonate,

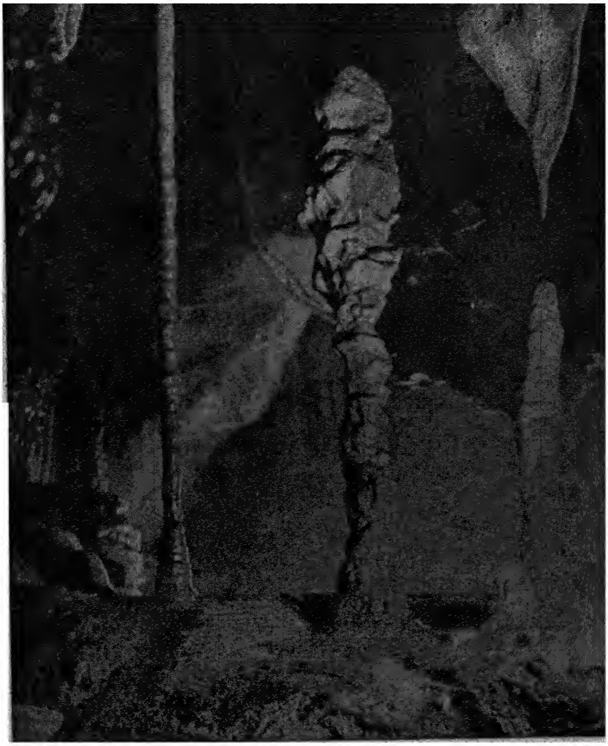


*Photo : W. F. Taylor.*

Stalactites and stalagmites in cave in Cheddar Gorge

filter, and test the filtrate with soap solution to see if an immediate lather is formed.

Owing to the fact that the hardness due to the Bicarbonates of Calcium and Magnesium can be got rid of by boiling it is called "**temporary hardness.**" The above experiments should explain to you the formation of the "fur" inside kettles when the water used is hard water. *Can you suggest*

*the chemical nature of the "fur" inside the kettle?* Obtain some and test it.

In chalk and limestone districts caves are found in which there are stalactites "growing" from the roof and stalagmites "growing" from the floor. The illustration shows such a cave in Cheddar Gorge (Somersetshire). In the light of what you have already done *can you suggest how these "growths" are formed? How would you obtain* (a) *Carbon Dioxide,* (b) *quicklime, from a piece of a stalactite?*

Another cause of the hardness of water is the presence in solution of the Chlorides and Sulphates of Calcium and Magnesium.

(iii) Make a solution of one of these salts in distilled water. Test a little with soap solution to find out whether or not it is hard. Boil the rest for some time. *Is any precipitate formed?* Test the boiled solution to find out if the hardness has been removed by boiling.

The hardness due to the presence of the Chlorides and Sulphates of Calcium and Magnesium is called "**permanent hardness**" because this cannot be got rid of by boiling.

(iv) **To soften "permanently" Hard Water**—The so-called permanent hardness of water can be got rid of by converting the soluble Chlorides and Sulphates of Calcium and Magnesium into the insoluble Carbonates. This can be done by adding a solution of washing soda to permanently hard water. In the experiment use about 25 c.c. of the permanently hard water and add excess of Sodium Carbonate (washing soda) solution. Filter off the white precipitate and test the filtrate with soap solution. The immediate formation of a lather indicates that the water has been softened.

$$\text{Calcium Sulphate} + \text{Sodium Carbonate} \rightarrow \text{Calcium Carbonate} \downarrow + \text{Sodium Sulphate.}$$

**It is the presence of the soluble Calcium and Magnesium salts that causes the hardness of water. Bicarbonates of these metals cause temporary hardness, and the Chlorides and Sulphates of these metals cause permanent hardness.**

**To make a sample of Soap**—Take a piece of mutton suet, heat it to melting-point and strain through a piece of muslin.

Put a tablespoonful of the fat into a 200 c.c. beaker and add about 50 c.c. of a 10 per cent. solution of Caustic Soda (fig. 25). Blow steam through for about an hour or until a clear brown solution is obtained. Add a saturated solution of common salt. The soap which is insoluble in the brine separates out as a cake on the surface. This should be skimmed off and pressed into a crucible or other mould.

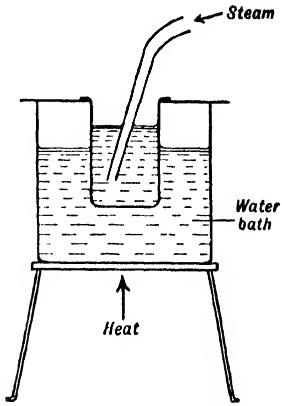



FIG. 25.—Apparatus for making a sample of soap

Mutton fat contains Stearic Acid; the soap you have just made may be regarded as the Sodium salt of the acid. Sodium Stearate is soluble in water and will form a soap solution. When Calcium and Magnesium salts react with soap, Calcium or Magnesium Stearate is formed. These salts are insoluble in water and form a curd.

In the case of temporarily hard water

Calcium Bicarbonate + Sodium Stearate → Calcium Stearate + Sodium Bicarbonate
(soluble) (soluble) (insoluble curd) (soluble)

In the case of permanently hard water

Calcium Chloride + Sodium Stearate → Calcium Stearate + Sodium Chloride
(soluble) (soluble) (insoluble curd) (soluble)

**In both cases you note that it is the insoluble Calcium Stearate that forms the curd.**

**A modern method for Softening Water**—Recently a new method for softening water has been discovered by using zeolites. These are substances which are found in the soil. They are formed by the weathering of felspars which are present in granite rocks. They can also be manufactured artificially from silicates of Aluminium, Sodium, and Potassium. The zeolites are placed in a tank and hard water is allowed

to flow through. It is here that an interchange takes place between the metals present in the zeolites and those in the salts causing the hardness of the water. The Magnesium and Calcium Sulphates and Bicarbonates are converted by the interchange into Sodium or Potassium Sulphates and Carbonates. Magnesium and Calcium are retained in the zeolites in place of Sodium or Potassium. Since Sodium and Potassium Carbonates do not cause hardness in water, thus the hard water is softened. After some time the zeolites are no longer able to interact. Brine is then run through the tank.

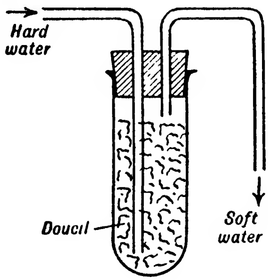



Fig. 26.—An experiment with a commercial water softener

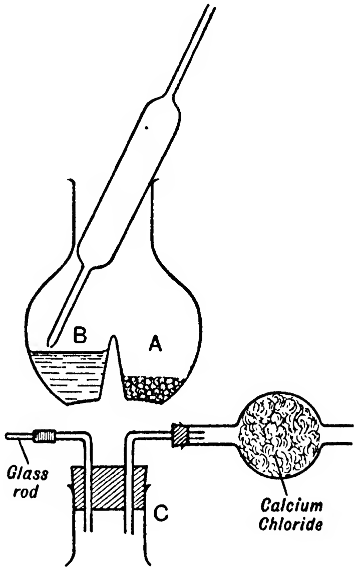



Fig. 27.—Apparatus to find percentage weight of Carbon Dioxide in a Carbonate

The action is now reversed, the zeolites give up Magnesium and Calcium for the Sodium in the brine. The tank is then washed through with water to remove the soluble Calcium and Magnesium Chlorides and the zeolite is ready to soften water again for a further period. It is very likely that the zeolites in the soil react with Calcium salts in a somewhat similar manner and provide Sodium and Potassium salts for the growing plant.

**Doucil** and **Permutit** are commercial products which may

be purchased as water softeners. Their action may be illustrated as follows :—

Fit up the apparatus shown in fig. 26. Pass hard water in and test the water which runs out to find out if it has been softened.

**Experiment 6**

**To find the percentage Weight of Carbon Dioxide in a Carbonate by acting on it with an Acid**—Weigh the divided flask [1] fitted with stopper C (fig. 27). Take out the stopper, turn the flask on its side and introduce about a teaspoonful of powdered Calcium Carbonate [2] into A, being careful not to allow any to get into B. Replace the stopper and weigh again. By means of a pipette run about 20 c.c. of dilute Hydrochloric Acid into B. Replace the stopper and weigh. Tilt the flask so that the acid reacts with the carbonate. The Carbon Dioxide escapes through the Calcium Chloride tube, where it is dried. When the reaction is complete remove the glass rod and draw air through the apparatus for a few seconds. *Why do you think this is necessary?* Replace the glass rod and weigh. Enter results as follows :—

| | |
|---|---|
| Weight of flask . . . . . . . . . | grm. |
| ,, ,, ,, and carbonate . . . . . | grm. |
| ∴ weight of carbonate . . . . . . . | grm. |
| Total weight of flask, acid, carbonate, before reaction | grm. |
| ,, ,, ,, ,, and contents after reaction . | grm. |
| ∴ weight of Carbon Dioxide . . . . . . | grm. |
| ∴ % weight of Carbon Dioxide in the carbonate . | grm. |

Compare the result obtained when Calcium Carbonate is used with that obtained in Experiment 1, p. 27.

**Carbon Dioxide**—You have learned that Carbon Dioxide is obtained from chalk by heating strongly or by the action of dilute acids on it.

Prepare Carbon Dioxide by the action of Hydrochloric Acid on marble (fig. 28) and perform the following experiments :—

(i) Test its effect on litmus.

[1] Obtainable from Messrs Philip Harris & Co., Ltd.

[2] A variety of carbonates may be used by various groups of pupils.

(ii) Find out whether or not the gas burns or allows things to burn in it.

(iii) Invert a jar of Carbon Dioxide over a jar of air and allow to stand for some time. Find out which contains Carbon Dioxide. *What does this show?*

Owing to the heaviness of Carbon Dioxide care must be taken to ensure that the gas does not accumulate in the cellars of a house. Careful ventilation is necessary.

(iv) Burn a little petrol in an evaporating dish placed on a sand tray. Pour on to it Carbon Dioxide from two gas jars as shown (fig. 29).

It is impossible to extinguish a petrol fire with water, as the petrol floats on the water. Contact with the Oxygen of the air must be cut off, and this is done by the heavy layer of Carbon Dioxide which rests on the petrol sufficiently long to choke out the flame. This property is made use of in fire-extinguishers.

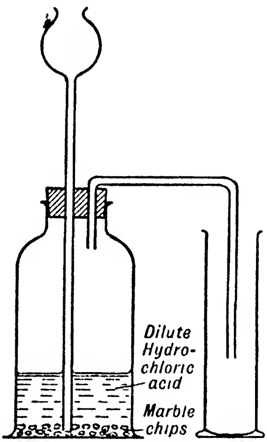



Fig. 28.—Preparation of Carbon Dioxide

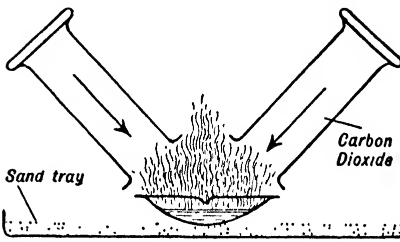



Fig. 29.—Extinguishing a flame with Carbon Dioxide

Fig. 30 shows one type of fire-extinguisher which contains a glass vessel holding Sulphuric Acid. When required the extinguisher is inverted and the lead weight breaks the glass vessel and sets free the Sulphuric Acid. This acts on the solution of Bicarbonate of Soda, large quantities of Carbon Dioxide are evolved, and a considerable pressure is developed. This forces a jet of liquid containing much Carbon Dioxide through the nozzle and a small fire is quickly extinguished.

In other forms of extinguishers the glass tube is broken by striking some part. The chemical principle underlying the working of the extinguisher is the same in all cases.

**Soda-water** contains Carbon Dioxide dissolved in water under pressure. Heat a little soda-water in a test-tube and pass the gas evolved into lime-water. The same test may be applied to " mineral " waters. These effervescing drinks all contain Carbon Dioxide under pressure, and when the pressure is released bubbles of the escaping gas produce the familiar frothy appearance.

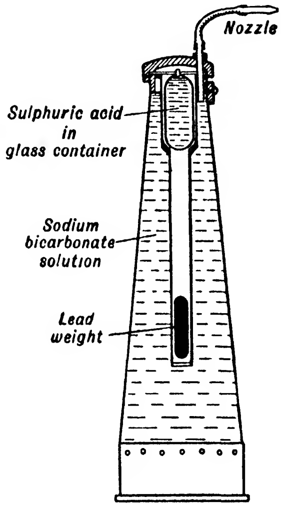



FIG. 30.—A type of fire-extinguisher

White, solid, snowlike Carbon Dioxide which evaporates at a temperature of $-79°$ C. is useful for producing low temperatures and is used in some minor surgical operations. It can be made by allowing the gas to escape through muslin tied over the exit of a cylinder containing liquid Carbon Dioxide under pressure. You should refer to the Biology Section for the importance of Carbon Dioxide as a food material for plants.

## QUESTIONS

1. What is quicklime ? How is it made from chalk ? What happens when cold water is slowly added to a lump of quicklime ? Can quicklime be obtained by heating the product of the action of water on quicklime ? Say why.

2. Describe carefully the action of Carbon Dioxide on lime-water. What happens if the final product is (*a*) boiled, (*b*) treated with soap solution ?

3. What is meant by " Hard " water ? Into what classes is this " hardness " divided and what substances cause each class of hardness ? Why is water softened for laundry purposes ? Describe briefly the methods used.

4. If a little Carbon Dioxide is passed into a clear solution of lime-water a white precipitate is formed. What is this white precipitate? Give three distinct methods by which a clear solution may be obtained from the "milky" solution.

5. How is mortar made? Why does mortar get harder with age? Suppose you added some dilute acid to old mortar what would you expect to happen? Describe any test you might apply to support your statement.

6. Describe carefully any experiment by which it can be shown that chalk contains 44 per cent. by weight of Carbon Dioxide. How can the presence of chalk and lime be detected in a mixture containing only these two substances? Indicate how the percentage composition of this mixture can be determined.

7. How can you distinguish between: (*a*) Chalk and Lime, (*b*) Caustic soda and Washing-soda, (*c*) Iron Oxide and Copper Oxide, (*d*) Hydrochloric Acid and Nitric Acid?

8. Classify the substances named below, using the following classes and properties: element, compound, mixture; metal, non-metal; acid, base, salt; behaviour with cold water; ability to burn in air.

   Carbon, Quicklime, Lead, Steam, Washing-soda, Chalk, Hydrogen Chloride, Gunpowder.

9. What are (*a*) stalactites, (*b*) stalagmites, and how are they formed?

10. Describe the preparation and state the principal properties of Carbon Dioxide. Explain the principle of a fire-extinguisher.

# CHAPTER V

## HEAT AND TEMPERATURE

**Heat and Temperature, Latent Heat, Units of Heat, Experiments to find the Melting-point of a Solid, Simple Experiments on Evaporation, Humidity and Health**

POUR 500 c.c. of water into a 2-lb. syrup tin and 250 c.c. into a 1-lb. syrup tin. Support each in turn on a tripod-stand and heat by means of a Bunsen flame (fig. 31) until the water has been boiling for two or three minutes. The same flame should be used for this purpose so that each quantity of water receives heat at the same rate. Stir well and take readings of the temperature each half minute. When the water has boiled for four or five minutes remove the can from the stand, allow to cool, and measure the water remaining. The amount of water at the beginning and end of this experiment will be required for calculation in Chapter VI. Plot your results on the same graph, with temperatures vertical and times horizontal.

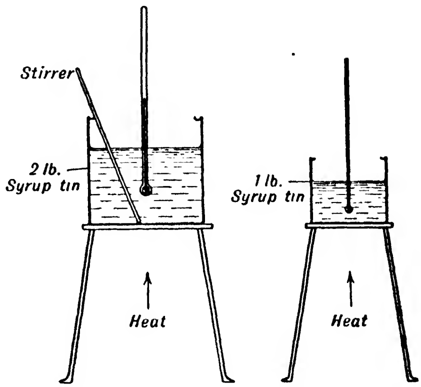



FIG. 31.

*As the same flame was used in heating the two cans each received heat at the same rate. Which quantity of water boiled in the shorter time? Is this what you would expect?* From the graphs calculate the rise in temperature per minute in each case. This is best done by using the straight part of

each graph. For instance, in fig. 32 the larger quantity of water rose in temperature BC degrees in AB minutes. Assuming that each received the same amount of heat per minute the experiment shows clearly that **equal amounts of heat may cause quite different rises in temperature when supplied to different bodies.**

*What do you notice about the temperature when the water was boiling?* Heat was still being supplied to the water. *Can you suggest what became of this heat?*

This part of the experiment shows that under certain conditions **heat may be given to a body without raising its temperature.** In the case of the boiling water this heat was used in turning the water into steam, *i.e.* **in changing the state of the water from liquid to vapour at the same temperature.**

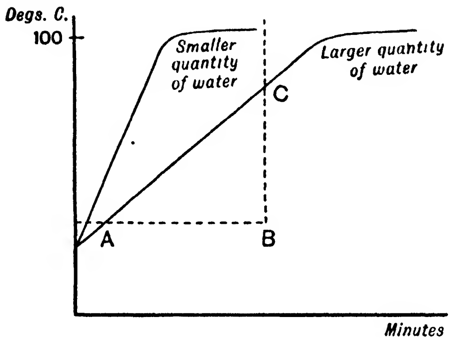



FIG. 32.

You will remember that when testing the lower fixed point of a thermometer you immersed it in pure melting ice.[1] This remained at a temperature of 0° C. although it was surrounded by air at a higher temperature. The heat which the ice absorbed from the air was used in melting it without raising its temperature. In this case the heat was used in **changing the state of the ice from solid to liquid at the melting-point.**

Heat which is absorbed by a body without raising its temperature is called *Latent Heat.* (The word *Latent* means *hidden.*) Latent heat is always absorbed when a body changes its state from solid to liquid (**latent heat of fusion**) or from liquid to vapour (**latent heat of vaporisation**). When the change of state takes place from vapour to liquid or from liquid to solid the latent heat is given out again.

[1] See Part I, Chapter X.

**Effects of Latent Heat in Nature**—During cold weather you have probably heard people say " It will be warmer after snow has fallen," and this is usually found to be true. When the water vapour in the atmosphere freezes forming snow, latent heat of vaporisation and of fusion is released, warming the atmosphere.

When rain has fallen the atmosphere is also often warmer, partly owing to the release of latent heat of vaporisation. When the water on the ground evaporates, the surrounding air helps to supply the latent heat necessary and so is cooled. In summer-time evaporation from the leaves of plants helps to keep them cool.

It is a bad thing to water a garden during brilliant sunshine because the rapid evaporation chills the soil and injures the sensitive plants.

In the desert an unglazed earthenware jar called a Goulash is used for keeping drinking-water cool and fresh. Water slowly evaporates from the outer surface, extracting heat in the process from the water inside the jar. The same principle operates in butter-coolers.

The experiments you have performed should put you on your guard against a very common error, namely, the confusion of **heat** and **temperature.** The confusion is partly due to the persistence of such terms as " red heat " and " white heat," etc., which really refer to **temperature** and not to **heat.** In old-fashioned thermometers you may find a certain temperature marked " blood heat " ; it marks the normal temperature of the human body. The temperature of all persons in normal health is practically the same. A person's temperature is usually taken by placing the bulb of a clinical thermometer under his tongue or in his armpit.

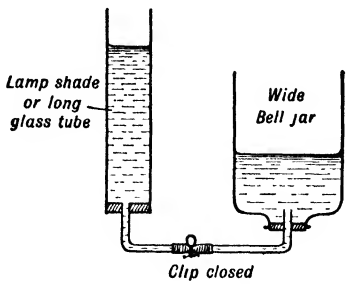


FIG. 33.

Fit up the apparatus shown in fig. 33. Close the clip and pour about half a pint of water into the narrow glass tube

and a pint into the bell jar. The water in the narrow tube should then be at the higher level, as shown. Open the clip. *What happens and why?* Repeat with the water in the bell jar at the higher level before the clip is opened. The water flows from the vessel in which it is at the higher level, irrespective of whether the **quantity** of water is greater or less in this vessel. In the subject of heat and temperature **heat** corresponds to the **quantity** of the water in your experiments and **temperature** to the **level** of the water. Just as it is the **difference in level** which causes a flow of water, so it is the **difference in temperature** which determines the passage of heat from one body to another.[1]

Just as water-level has a different kind of unit from quantity of water, so heat-level or temperature has a different kind of unit from quantity of heat. Temperature is measured in degrees Centigrade or Fahrenheit, and the units of heat will now be defined.

**Units of Heat**—The scientific unit of heat is called the calorie. **A calorie is the quantity of heat which will raise the temperature of a grm. of water 1° C.** (The British Thermal Unit will be dealt with later.)

*How many calories will raise the temperature of*

(a) 20 *grm. of water through* 10° *C.?*
(b) 40 ,, ,, ,, 8° *C.?*
(c) 100 ,, ,, ,, 40° *C.?*

*Through how many degrees C. would* 1000 *calories raise the temperature of*

(a) 100 *grm. of water?*
(b) 25 ,, ,, *?*
(c) 40 ,, ,, *?*

From the graphs illustrating the results of the experiments with tins of water you have already found the rise in temperature per minute for each quantity of water. Now calculate how many calories per minute were absorbed by the water in the two experiments.

The fact that the temperature of a substance does not alter

[1] Provided that there is no chemical action between them.

whilst it is changing its state enables us to find accurately melting- and boiling-points.

**Experiment to find the Setting-point (Melting-point) of a Solid**—Place in a boiling tube enough naphthalene to cover the bulb of a thermometer. (Naphthalene is obtained from coal-tar and is in general use as "moth balls.") Warm the tube in a bath of boiling-water and keep it there until the substance has melted and the temperature is about 100° C. Rapidly transfer the boiling tube and contents to an empty beaker (fig. 34) and take readings of temperature every minute until this has fallen to about 50° C. Plot the results on a graph (fig. 35). Explain the shape of the graph and from it find the setting-point of the solid.

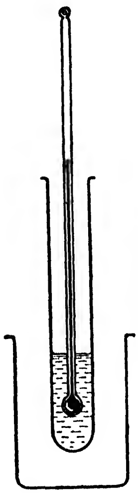


FIG. 34.

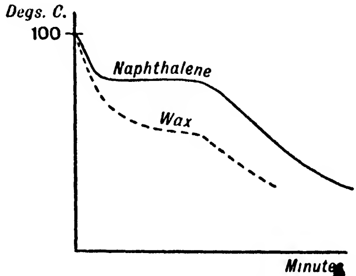



FIG. 35.

Repeat the experiment, using paraffin wax. In this case allow to cool to about 35° C.

*Do you notice any difference in the general shape of the graphs ?*

Naphthalene is a substance of known definite chemical constitution, whereas wax is a mixture of several substances, which differ slightly in their setting-points. Consequently the setting-point of wax is less definitely marked than that of naphthalene.

**Simple Experiments on Evaporation**—(1) Dip your hand in water. Wave it about in the air. *What do you notice whilst the water is evaporating ?* If the doctor wishes to reduce your temperature when you have a chill he gives you medicine to make you sweat. The evaporation of the sweat causes you to become cooler.

(2) Place in turn a few drops of (i) methylated spirits, (ii) ether on the back of your hand. Explain what you observe.

(3) Direct a current of air from a cycle-pump on to the bulb of (i) a dry thermometer, (ii) a thermometer the bulb of which is wrapped in muslin moistened with water. Explain what happens.

(4) When you come out of the water after a bathe, before drying yourself you feel much colder than when standing in the water. Explain this fact.

(5) Take the air temperature by means of a thermometer which has lain on the bench for a few minutes. Wrap the bulb in a little cotton-wool. Dip this into some methylated spirits, which has stood in the room in a closed bottle and which is thus at the air temperature. Record and explain what happens as the liquid evaporates. Repeat, dipping the bulb in ether.

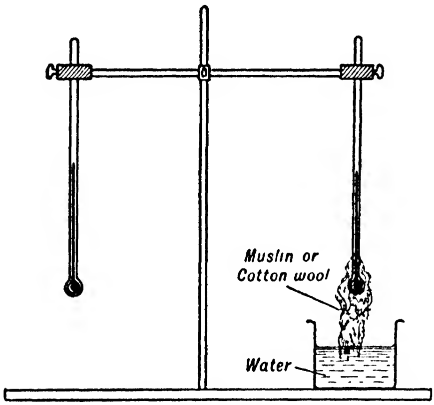



FIG. 36.

(6) Arrange two thermometers side by side on a stand and observe if they read alike. Try to select two which do not differ by more than 0·5° C. Wrap the bulb of one in muslin or cotton-wool which dips into some water in a beaker or metal vessel (fig. 36). Take readings of the two thermometers after standing them for five minutes in

(*a*) the laboratory

(*b*) the playground (i) in the shade

(ii) in the sun.

Explain what is noticed.

(7) Place the two thermometers underneath a large inverted glass tank which is placed above a flat shallow dish of water, so that the space above soon becomes saturated with

moisture (fig. 37). Read the thermometers after leaving them for some hours. *Do the thermometers now read differently?* Explain.

The experiments show clearly that **evaporation causes cooling,** because heat is required to bring about evaporation. In the last experiment, as the space around the thermometers was saturated with vapour there was no evaporation from the "wet bulb" thermometer, and consequently no cooling. Thus the "wet bulb" and "dry bulb" thermometer read the same.

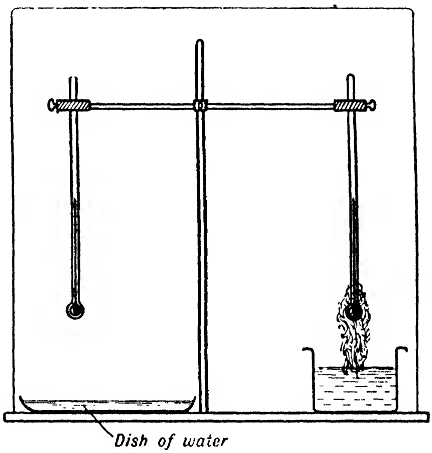



FIG. 37.

When the atmosphere is very damp and there is little or no wind we have a "bad drying day" for clothes, which have to be brought into the house and dried by the fire. A windy day is usually a good drying day, for the wind carries away the moist air which has resulted from the evaporation of water from the clothes, replacing it by drier air. Wet and dry bulb thermometers are used to determine the amount of water vapour in the atmosphere. This has an important bearing on health.

**Humidity and Health**—You are aware of the stuffy feeling which may exist in a classroom of which the doors and windows are closed. This is partly due to the fact that the air is then saturated with water vapour and partly to the increase in the amount of Carbon Dioxide. As you breathe you expel water vapour and Carbon Dioxide from your lungs. Also water vapour is constantly passing out through the pores of the skin. The human body is very much like an engine. It takes in fuel in the form of food. This is partially converted

into fats and sugars which act as fuel. The "burning" of this fuel by the oxygen absorbed by the lungs causes heat to be evolved. This maintains the body temperature by making up for the heat lost from the surface of the skin. When taking violent exercise the fuel is burned faster and the heat has to get away faster to prevent the body temperature rising. If the heat cannot get away fast enough you begin to sweat, and when the perspiration evaporates the skin is greatly cooled. If the air is saturated with water vapour even sweating will not cool you, as then the perspiration cannot evaporate.

It is important to realise that men can stand *dry* heat when the temperature is far above the normal boiling-point of water. A man has been known to stay for five minutes in a hot cooking oven, only coming out when his hair began to singe. In tropical countries if the temperature of the atmosphere saturated with moisture is 75° F. or above, a man is unable to do hard manual work. In coal mines the air is usually hot and fairly dry. The miner has to get rid of his heat by sweating, and many lose several pounds in weight during a shift. It is said that the sweating record is held by an Englishman who lost 18 lb. (1·8 gallon) in $5\frac{1}{2}$ hours. To make up for loss of sweat during their work, coal miners drink water in which a little common salt is dissolved.

## QUESTIONS

1. Heat may be given to a body without changing its temperature. State the conditions for this to happen and give two examples.
2. Briefly explain the difference between "heat" and "temperature."
3. Water kept in a jar of porous earthenware is usually cooler than the surrounding air. Explain this.
4. Why is it that during a thaw the atmosphere feels bitterly cold ?
5. Define the calorie. 500 calories raise the temperature of some water 25° C. How much water is there ?
6. Describe an experiment to find the melting-point of a solid such as naphthalene or beeswax.
7. Describe and explain an experiment which shows that evaporation produces cooling.

# CHAPTER VI

## LATENT HEAT. THE STEAM-ENGINE

### Experiments to Measure the Latent Heat of Steam. The Steam-Engine

**An experiment to find approximately the Number of Calories which will evaporate 1 grm. of Water at the Boiling-point**[1]— Measure 400 or 500 c.c. of tap-water into a 2-lb. syrup tin The water should not fill more than two-thirds of the tin. Place the tin on a tripod-stand. Take the temperature of the water and then place under the tin a Bunsen burner which has been turned down to consume about half its normal gas supply. Take readings of the temperature every half-minute until the water has been boiling for four or five minutes. Remove the burner and allow the water to cool. Then measure the water which remains so as to find how much has boiled away. Plot the readings on a graph—temperature vertically and time horizontally (fig. 38).

(1) *Into how many parts can you divide the graph ?*

(2) *What shape is the part up to* 65° *C. or* 70° *C. ?*

(3) From this part calculate the average rise of temperature per minute Hence calculate the number of calories absorbed by the 400 grm. of water per minute.

(4) Produce the straight parts of the graph until they meet at A. Assume that the water commenced to evaporate at the point A. It has been visibly evaporating from part C, as you must have noticed. *How many minutes are shown on your graph from* A *to* B ? Hence find the number of calories which would evaporate 1 grm. of boiling-water. Write down also the average result of the class. The results of an actual experiment are shown plotted and worked out in fig. 38.

The experiment you have performed is not a very accurate one, but it shows the enormous amount of heat necessary to

[1] The data and curves plotted in Chapter V can be used here.

evaporate 1 grm. of water.[1] The correct result is 540 calories, enough heat to raise the temperature of 540 grm. of water 1° C.

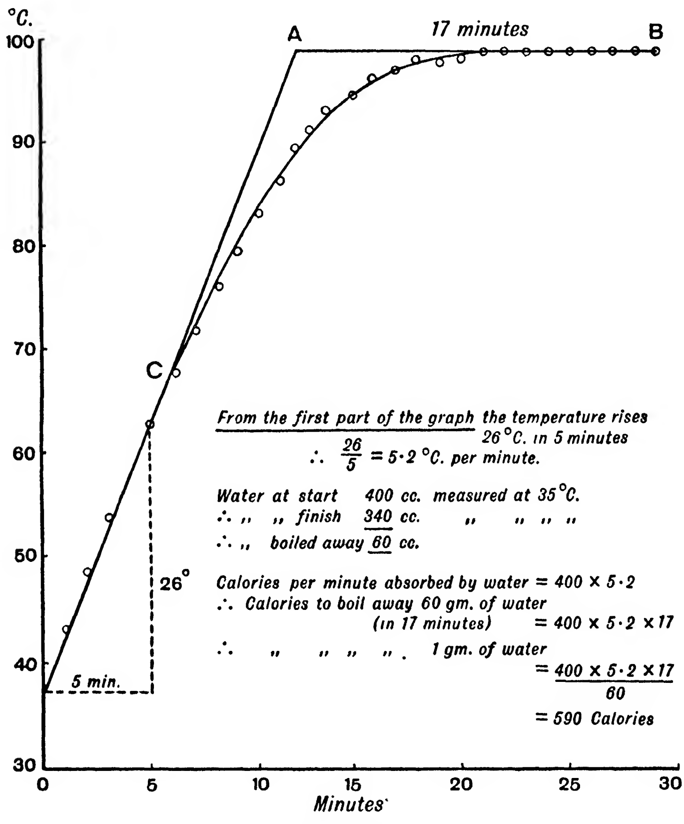



FIG. 38.—Finding the number of calories necessary to evaporate 1 grm. of water at its boiling-point

**This heat is given out again when 1 grm. of steam at 100° C. condenses to water at 100° C.** and is called the **Latent Heat of steam or the Latent Heat of vaporisation of water.** Your body temperature is 98·4° F. This is 37° C. approx. If

[1] A more accurate experiment will be described in the next chapter.

1 grm. of water at 100° C. was splashed on your hand it would only give out $100 - 37 = 63$ calories in cooling to your body temperature. But if 1 grm. of steam at 100° C. condensed on your hand it would give out 540 calories in *condensing* to water at 100° C. and also 63 calories in cooling to 37°, *i.e.* $540 + 63 = 603$ calories in all. It is no wonder that scalds from condensing steam when a boiler explodes often cause death.

**An experiment to find approximately the Latent Heat of Fusion of Ice, *i.e.* the Heat which will melt 1 grm. of Ice at its Melting-point**—Using a pestle and mortar crush some ice into very small pieces. Nearly fill a beaker or metal vessel of about 200 c.c. capacity with the crushed ice. Support it over a *small* flame as shown in fig. 39.[1] Stir constantly and take temperature readings every minute until all the ice has melted and the resulting water has risen to about 40° C. or 50° C. in temperature. Plot the readings on a graph (fig. 40). From part AB find the rise in temperature of the *water* formed per minute. *How many calories were absorbed by* 1 *grm. of the water per minute?* Each grm. of ice must have absorbed heat at the same rate, for it was heated by the same constant source of heat.

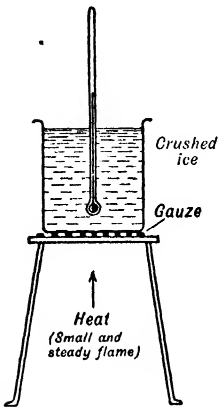



FIG. 39.

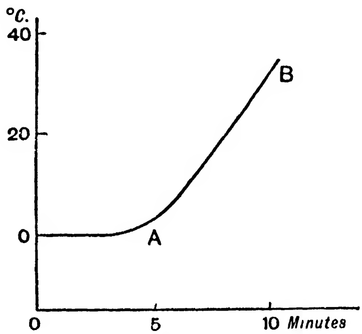



FIG. 40.

[1] A hot plate electrically heated may be used.

On the graph carefully measure the time 0A during which the ice was melting. Take the point A as the intersection of the two straight parts of the graph. From this and your last result find the number of calories which melted 1 grm. of ice.

The results for different members of the class should be written on the blackboard and averaged out. The correct result is 80 calories per grm., *i.e.* 1 grm. of ice at 0° C. requires 80 calories to melt it without rise of temperature. The manner in which the latent heat of ice was first found by an Englishman, Joseph Black (1728–1799), is interesting. In a large empty hall, where the temperature was practically steady, he hung two globes of equal size, one containing 5 ounces of water at a temperature of 0·55° C. and the other containing 5 ounces of ice at 0° C. In each he had a delicate thermometer. The room temperature was 8·33° C. In half an hour the water had risen in temperature to 4·44° C., but the ice took ten and a half hours to reach the same temperature, or twenty-one times as long as the water. Thus in half an hour each grm. of water had absorbed $4{\cdot}44 - 0{\cdot}55 = 3{\cdot}89$ calories. Therefore each grm. of the ice had absorbed in ten and a half hours $21 \times 3{\cdot}89 = 80{\cdot}69$ calories. But at the end of the experiment the ice was 4·44° C. above the melting-point. Therefore in melting, alone, 1 grm. of ice had absorbed $80{\cdot}69 - 4{\cdot}44 = 76{\cdot}25$ calories. The mean of a large number of experiments by this and other methods gives 80 calories per grm. for the latent heat of fusion of ice.

**Keeping things Cool on Ice**—The fact that ice requires heat in order to melt it is of considerable domestic importance. Several instances will occur to you; for example, ice-cream carts, the fishmonger keeping fish on ice, iced lemonade in hot weather. The reason why we can get fresh fruit and meat from overseas is because cold storage is now universal on modern ships, which are fitted with refrigerating plant. In all these cases latent heat is the determining factor.

**The Steam-Engine**—When boiling-water is converted into steam latent heat is absorbed. The steam, at atmospheric pressure, occupies about 1600 times the volume of the water,

and if confined in a smaller space it exerts a great pressure which may be used to move a piston. In this way the heat energy absorbed is converted into mechanical energy.

In 1687 a Frenchman named Papin showed in London a machine by which steam, in condensing, produced a partial vacuum, and he showed how this could be applied in an engine. He may thus be regarded as "the father of the steam-engine." Fig. 41 shows his engine, and how it works will be clear from the following explanation.

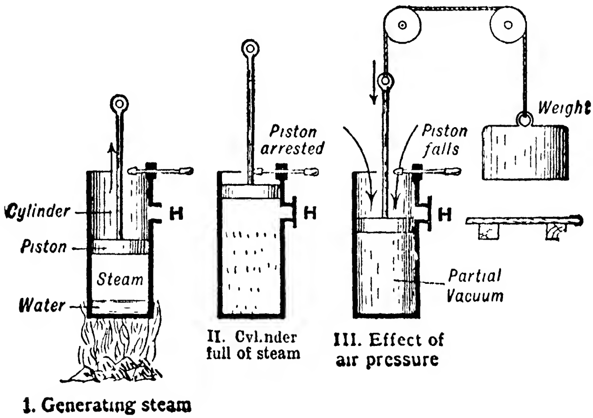



FIG. 41.—Papin's engine

The cylinder, containing a little water, is placed on the fire. The steam generated forces up the piston and drives out any air through a small hole H. This is then plugged and the cylinder removed from the fire. The piston is next attached to a heavy weight by a rope passing over pulleys. Cold water is then poured on to the cylinder, the steam inside condenses and makes a partial vacuum. The air-pressure drives in the piston, raising the weight.

Papin talked and wrote of the possibilities of this machine, and soon it came to the ears of two men who were seeking for a method of overcoming the flooding of coal mines in the north of England. Thousands of horses were employed to keep these dry by pumping the water. More power was needed to do

this effectively. The two men were Savery and Newcomen, and the outcome was first Savery's and then Newcomen's pumping-engine (fig. 42).

In Newcomen's engine steam was passed into a cylinder, the piston of which was connected to the pump as shown. After the piston was pushed up, the steam was turned off and cold water was poured on the cylinder, with the result that the pump-piston was raised and the water eventually poured out of the spout.

Newcomen and Savery found by an accidental leak that it was better to condense the steam by spraying water *inside*

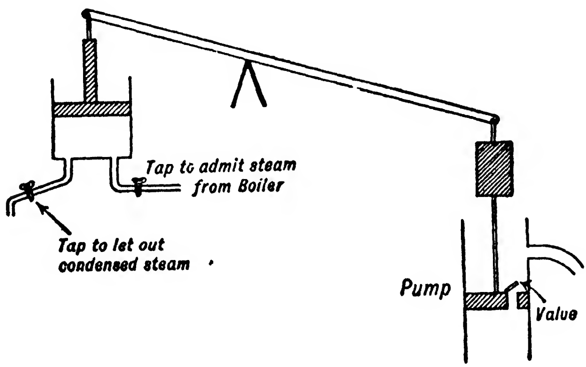



Fig. 42.—Newcomen's engine

the cylinder. Soon valves were fitted to let in the steam and remove the water formed. For many years this type of engine did good service in making work in the mines possible.

Then arose another genius, James Watt, an instrument-maker of Glasgow. For many years Watt had studied the properties of steam, and it was whilst engaged in repairing a Newcomen engine that the idea of a separate condenser flashed on his mind. He saw at once that this would result in much greater efficiency, and so the modern steam-engine was born.

The working of the steam-engine is clearly shown in fig. 43. The steam is generated in a boiler, where hot gases formed from burning coal heat water as they pass through many tubes. The

steam passes into the steam chest and then enters the cylinder through either the right or the left port. The slide valve automatically arranges for one port to be open to the steam and the other to the exhaust (see below). The used steam

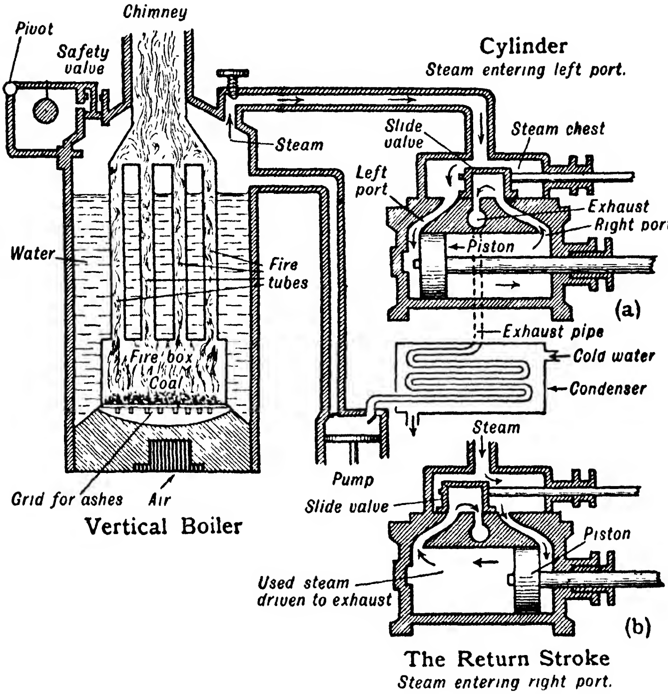



FIG. 43.—Diagrammatic representation of a steam-engine

is condensed in a separate vessel called the Condenser, and is pumped back into the boiler.

Watt also jacketed the cylinder with badly conducting materials, so reducing loss of heat. It was Watt who made the engine double-acting, the piston being driven to and fro by the steam admitted at either port. In Newcomen's engine the piston was forced back by the pressure of the atmosphere.

The working of the piston and slide valve are best studied

from a model steam-engine. The piston causes a fly-wheel to revolve. On the shaft of the fly-wheel is fitted an "eccentric" which drives the slide valve backwards and forwards. The slide valve is shown in fig. 43 (*a*) covering the right port, and in fig. 43 (*b*) covering the left port.

A safety-valve is always fitted to the top of the boiler. When the pressure gets too high this valve lifts and allows steam to escape.

## QUESTIONS

**1.** 100 grm. of ice at 0° C. are stood in a thin vessel on a hot plate and well stirred. The ice melts in 20 minutes and then the water formed rises in temperature 20° in 5 minutes. Calculate (*a*) the number of calories absorbed per minute, (*b*) the heat to melt 1 grm. of ice.

**2.** 50 grm. of water are raised in temperature from 0 to 100° C. in 5 minutes and are boiled away completely 27 minutes later. Calculate (*a*) the number of calories absorbed per minute, (*b*) the heat to evaporate 1 grm. of water.

**3.** Find the resulting temperature on mixing in a bath:

| | | | | | | |
|---|---|---|---|---|---|---|
| (*a*) 6 | gallons of water at | 80° C. | with | 10 | gallons at | 15° C. |
| (*b*) 5 | ,, ,, | 60° C. | ,, | 8 | ,, ,, | 20° C. |
| (*c*) 4 | ,, ,, | 30° C. | ,, | 10 | ,, ,, | 50° C. |

*Solution of* (a):

[The result will be the same if 6 grm. at 80° C. were used with 10 grm. at 10° C.]

Let $t$ = final temp.

Heat gained = Heat lost

$$\therefore 10(t - 15) = 6(80 - t)$$
$$10t - 150 = 480 - 6t$$
$$16t = 630$$
$$t = 39{\cdot}4° \text{ C.}$$

# CHAPTER VII

## THERMAL CAPACITY AND SPECIFIC HEAT

### Thermal Capacity, Specific Heat, more accurate experiments on the Latent Heat of Steam, British Thermal Units, Calculation of Therms from Gas-Meter Readings

At some time in your life you have probably placed a piece of hot jam-roll in your mouth and burnt your tongue with the jam. Both jam and suet were at the same temperature and perhaps you have wondered why the jam and not the suet felt the hotter. The explanation of this requires a knowledge of thermal capacity, with which we shall deal in this chapter.

The water of seas and lakes remains comparatively cool whilst the temperature of the land becomes comparatively high during a hot summer's day. In winter the temperature of large land masses may be much lower than that of the sea, factors which are of importance in determining climate. These phenomena also require a knowledge of thermal capacities for their explanation.

**Supposing we supply heat at equal rates to equal volumes of different substances, would the temperature of each rise at the same rate?** Let us find out by experiment. By means of a burette run out 20 c.c. of mercury and water into glass specimen tubes (about 3 in. × 1 in. diameter). Through the bung of each pass a thermometer reading to about 100° C. which dips into the liquid. Take the temperature of the liquid and then plunge the tube into some boiling-water in a beaker (fig. 44). Hold the tube by the thermometer and move it about so that the liquid is agitated. Take temperature readings every ten seconds[1] until the temperature is about 80° C. Plot the results for the liquids on one sheet of graph paper (fig. 45).

[1] One member of the class should be detailed off to give a signal "ready" and hit the bench with a ruler every 10 seconds.

Arrange the liquids in order according to the quickness with which they warm up.

The relative density of mercury is 13·6. In the experiment 20 c.c. of each liquid were used. *What was the weight of* (a) *water,* (b) *mercury, used in the experiment?*

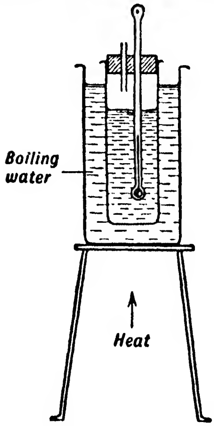



FIG. 44.

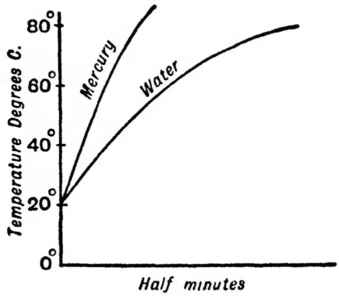



FIG. 45.

It is a remarkable fact that although the mercury weighs 13·6 times as much as the water its temperature rises much more rapidly.

*If you had equal* weights *of water and mercury, which would require the most* heat *to raise its temperature* 1° *C.?* Give reasons for your answer.

## Thermal Capacity

**The thermal capacity of a body is the quantity of heat which will raise its temperature one degree.** Thus the thermal capacity of 20 grm. of mercury will be twice that of 10 grm. of mercury.

The experiment you have performed shows that the thermal capacity of water is enormously greater than that of the same weight of mercury. Weight for weight, water has a much greater thermal capacity than any metal.

Another experiment which illustrates this fact is the following :—

A. Tie together two cubes of copper, each of 2 cm. side, and suspend them for about five minutes in some boiling-water. Lift them out of the water, allow them to drain for a second or so in the steam above the surface and then transfer them rapidly to 50 c.c. of cold water, the temperature of which has been taken. Stir well with the thermometer and note the resulting temperature.

B. Now take a quantity of water equal in weight to the weight of the two copper cubes used in A. Heat it until it boils and add it to 50 c.c. of cold water, the temperature of which has been taken. Stir well and take the temperature. Enter your results thus :

| | | |
|---|---|---|
| A. Temperature of hot copper | = | 100° C. |
| ,, ,, cold water | = | ° C. |
| ,, ,, mixture | = | ° C. |
| *Rise of temperature of cold water* | = | ° C. |
| B. Temperature of hot water | = | 100° C. |
| ,, ,, cold ,, | = | ° C. |
| ,, ,, mixture | = | ° C. |
| *Rise of temperature of cold water* | = | ° C. |

Compare the rise of temperature of the cold water in each case. The results show that water has a much greater thermal capacity than has the same weight of copper.

## Experiments in Measuring Thermal Capacity

You should now perform a series of experiments to measure the thermal capacity of several metals.

We shall assume that **when two substances at different temperatures are mixed together, the quantity of heat gained by the cooler body is equal to that lost by the hotter body.** This appears common sense, and is borne out by experiments on mixing quantities of water at different temperatures.

For experiments in heat a *thin* aluminium vessel, weighing only about 5 grm., which can be bought for a few pence at any hardware shop is very convenient. This *calorimeter* stands on a cork in a pint aluminium can which protects it

from draughts. Transfer 80 c.c. of cold water into the calorimeter. Take its temperature, estimating this to $\frac{1}{10}$° C. Stir the water well.

Fasten a piece of thread to a large cylinder or cube of metal and immerse it for a time in boiling-water. Allow the metal to drain for a second in the steam above the boiling-water and then transfer it rapidly to the calorimeter and stir the water until the temperature is steady. Read the temperature to $\frac{1}{10}$° C.

In working out results we shall assume that *all* the heat lost by the metal is gained by the water. Actually the calorimeter and thermometer gain some of the heat, but this can be neglected if the calorimeter is very light in weight compared with the water.

*Results :*

| Metal | Copper | | |
|---|---|---|---|
| | Experiment 1 | Experiment 2 | |
| Weight | 168 | 168 | grm. |
| Weight of water | 80 | 80 | grm. |
| *Temperatures :* | | | |
| Cold water | 15·0 | 14·5 | ° C. |
| Hot metal | 100·0 | 100·0 | ° C. |
| Mixture | 28·7 | 28·2 | ° C. |
| Rise of temperature of water | 13·7 | 13·7 | ° C. |
| Heat gained by water | 80 × 13·7 = 1095 calories | | |
| *This heat has been given out by the metal :* | | | |
| Fall of temperature of metal | 100 − 28·7 = 71·3 | 100 − 28·2 = 71·8 | ° C. |
| ∴ Heat lost by metal in falling 1° | $= \frac{1096}{71 \cdot 3}$ = 15·4 | $= \frac{1096}{71 \cdot 8}$ = 15·4 | calories |
| ∴ Thermal capacity | = 15·4 | = 15·3 | calories |
| Average result | 15·35 calories | | |

The experiment should be repeated with the same metal,

but using a fresh supply of water each time. Vary the amount of water, using 80, 90, or 100 grm.[1]

The method is called the *Method of Mixtures.* The results of the class should be written on the blackboard, one column being devoted to each metal (all the metals of one kind being the same weight). An average should be taken and entered in the student's notebook thus:

| Metal | Copper | Zinc | Aluminium | |
|---|---|---|---|---|
| Weight . . . | | | | grm. |
| Average thermal capacity | | | | calories |
| Thermal capacity of 1 grm. of substance | | | | calories |

The **Specific Heat** (or Specific thermal capacity) of a substance is

$$\frac{\textbf{Thermal capacity of substance}}{\textbf{Thermal capacity of the same weight of water}}.$$

The thermal capacity of 168 grm. of water = 168 calories. The thermal capacity of the copper in the results given on p. 62 is 15·35 calories. The specific heat of copper is therefore $\frac{15 \cdot 35}{168} = 0 \cdot 091$. This is a *number,* and is numerically equal to the thermal capacity of 1 grm. In the last line of the above table you have already calculated the specific heats of some metals.

*If you know the specific heat and the weight of a substance, how could you calculate its thermal capacity?*

[1] It will be convenient to use cylinders 1 inch × 1 inch or cubes of metal 2 cm. side for this experiment. The weights should be given or found by a spring-balance. Suitable metals are copper, brass, zinc, tin, lead, aluminium. By measuring the water in measuring cylinders and using spring-balances instead of beam-balances much time is saved and the student is enabled to concentrate on the study of heat. The loss in accuracy is small, whilst the gain in practice of measuring heat is great.

Fill in the following table :—

| Substance | Weight. grm. | Specific heat | Thermal capacity. cals. |
|---|---|---|---|
| Copper . . . | 300 | 0·095 | |
| Mercury . . | 200 | 0·030 | |
| Lead . . . | 100 | 0·033 | |
| Aluminium . . | 150 | 0·22 | |
| Turpentine . . | 250 | 0·45 | |
| Iron . . . | 50 | 0·12 | |

Careful experiments show that although the specific heat of a substance is practically constant over ordinary ranges of temperature, yet it does alter when the substance is strongly heated or cooled. Thus, for instance, the average specific heat of iron from 0–100° C. is 0·11, but from 0–1000° C. it is 0·15.

Our definitions of the unit of heat assumed that the specific heat of water is the same at all temperatures. This is not strictly true, but is near enough for practical purposes. **Accurately, the calorie warms 1 grm. of water from 15° C. to 16° C.** The specific heat of water has a minimum value at 40° C.

## To determine the Thermal Capacity and Specific Heat of a Liquid by using a Metal of known Thermal Capacity

Measure out 80 c.c. of the liquid. Proceed exactly as in the last experiment, find the relative density of the liquid by means of a hydrometer, and work out results as given on p. 65.

The results of your experiments show that water has a much greater specific heat than the solids and liquids you have tested. It is a fact that water has a much greater specific heat than any substance known, almost without exception. You should now be able to understand the reason for the phenomena mentioned in beginning this chapter. The jam of a jam-roll consists largely of water, so that it has a much greater thermal capacity than the suet. The wet jam also makes better contact with the tongue and in consequence its heat is the more easily felt.

| Liquid | Turpentine | | |
|---|---|---|---|
| | (*a*) | (*b*) | |
| Volume . . . . . | 80 | 80 | c.c. |
| Relative density . . . | 0·85 | 0·85 | |
| Weight . . . . . | 80 × 0·85 =68·0 | 80 × 0·85 =68·0 | grm. |
| Metal used | Copper | | |
| Thermal capacity . . | 15·3 | 15·3 | calories |
| *Temperatures :* | | | |
| Hot metal . . . | 100·0 | 100·0 | ° C. |
| Cold liquid . . . | 12·0 | 14 0 | ° C. |
| Mixture . . . . | 38·5 | 40·0 | ° C. |
| Fall in temperature of hot metal . . . . | 61·5 | 60·0 | ° C. |
| ∴ Heat lost by metal . . | 15·3 × 61·5 =941 | 15·3 × 60·0 = 918 | calories |
| *This heat is gained by the liquid :* | | | |
| Rise in temperature of liquid | 26·5 | 26 0 | ° C. |
| ∴ Thermal capacity of liquid | 941 ÷ 26 5 =35·5 | 918 ÷ 26·0 =35·4 | calories |
| ∴ Specific heat of liquid . | 35 5 ÷ 68 =0·52 | 35·4 ÷ 68 =0·52 | |
| Average . . . . . . . 0·52 | | | |

## A Calorimetric Method of measuring High Temperatures

The following method may be used in industry for estimating the temperature of a furnace or that of a hot oven. You should use it to measure the average temperature of a Bunsen flame.

Obtain and weigh an iron nut. Pour 80 or 100 c.c. of water into your calorimeter and take its temperature. Hang the iron nut on a stout piece of iron wire and hold it in the Bunsen flame until it is red-hot. Drop it into the water, stir well, and take the temperature. Taking the specific heat of the nut as 0·15 (an average value between 0° and 1000° C.) calculate the average temperature of the flame.

The following results were obtained by this method for the temperature of an electric furnace :—

*Weighings, etc.* :

| | |
|---|---|
| Weight of iron | $= 12{\cdot}85$ grm. |
| Thermal capacity | $= 12{\cdot}85 \times 0{\cdot}15 = 1{\cdot}93$ calories. |
| Weight of water | $= 54$ grm. |

*Temperatures* :

| | |
|---|---|
| Hot metal | $= t^\circ$ C. |
| Cold water | $= 8^\circ$ C. |
| Mixture | $= 48^\circ$ C. |
| Rise of cold water | $= 40^\circ$ C. |
| Fall of metal | $= (t - 48)^\circ$ C. |
| Heat gained by water | $= 54 \times 40$ calories. |

Heat lost = heat gained.

Heat lost by metal $= 1{\cdot}93\ (t - 48)$ calories

$\therefore \quad 1{\cdot}93\ (t - 48) = 54 \times 40,$

whence $\quad t = 1120^\circ$ C. approx.

## Experiments using Thick Calorimeters (Marshall's Method)

Thick calorimeters[1] of copper, iron, and aluminium may be obtained of the dimensions shown in fig. 46. Six of each metal are ample for class use. Each is surrounded by a detachable jacket of felt, which must be kept dry. Weigh one of these metal vessels to the nearest grm. by a spring-balance or on a robust pair of scales. (The felt cover must not be weighed.) Stand a thermometer in the vessel for a few minutes and note the temperature. Meanwhile measure out 150 c.c. of water and bring it to the boil in a tin can. As soon as it is boiling pour it carefully into the metal vessel, stir well with the thermometer, and note the resulting temperature.

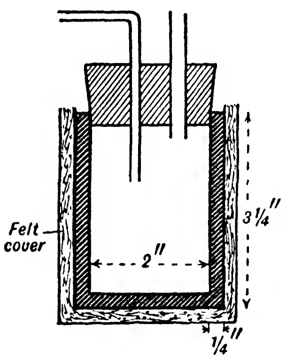



Fig. 46.—Thick calorimeter for use in heat experiments

[1] Designed by A. R. Marshall, H.M.I. Obtained from Messrs Philip Harris & Co., Ltd.

Assume that the temperature of the boiling-water was 100° C. and work out the thermal capacity and specific heat of the metal. Repeat the experiment, using another of the calorimeters of a different metal. Enter your results thus :

| Metal | Copper | Iron | Aluminium | |
|---|---|---|---|---|
| *Weights :* (*a*) metal . | | | | grm. |
| (*b*) water . | | | | grm. |
| *Temperatures :* | | | | |
| (i) Cold metal . . | | | | ° C. |
| (ii) Hot water . . | | | | ° C. |
| (iii) Mixture . . | | | | ° C. |
| Fall in temperature of hot water . . . | | | | ° C. |
| Rise in temperature of metal . . . | | | | ° C. |
| Heat lost by hot water . | | | | cals. |
| Thermal capacity of metal | | | | cals. |
| Specific heat of metal . | | | | |

## Water Equivalent

**The water equivalent of a body is the weight of water which has the same thermal capacity as the body.**

If a body has a thermal capacity of 20 *calories* its water equivalent is 20 *grm.*

## A more accurate Experiment on the Latent Heat of Steam

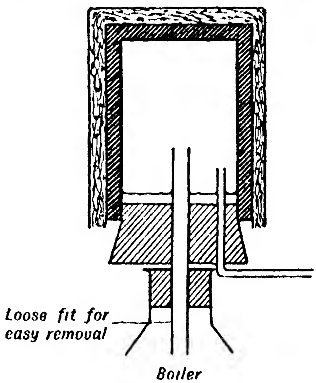


FIG. 47.

Take the temperature of one of the thick metal calorimeters. Fit it with a rubber bung through which pass two tubes.[1] Boil water

[1] Designed by A. R. Marshall, H.M.I. The tins and bungs may be obtained from Messrs Philip Harris & Co., Ltd. A set of six is sufficient for a class, as the bungs may be transferred from one metal vessel to another.

in a tin can fitted with a bung through which the straight glass tube fits loosely so that it can be removed with ease. When the water is boiling invert the metal vessel over the boiler as shown (fig. 47). When steam escapes really fast remove the vessel, cool, and measure the condensed steam in a burette.

*Results :*

| | | | |
|---|---|---|---|
| Weight of metal vessel | | = | grm. |
| Specific heat ,, | | = | |
| Water equivalent = . . . × . . . | | = | grm. |
| Temperature of vessel | Cold | = | ° C. |
| | Hot | = | 100° C. |
| ∴ *Heat gained by vessel* = . . . × . . . | | = | *calories* |
| Volume of steam condensed (by burette) | | = | c.c. |
| ∴ *weight* ,, ,, | | = | grm. |
| The water and steam were at 100° C. | | | |
| ∴ **Latent heat of steam** | | = . . . | |
| | | = | cals. per grm. |

**The British Thermal Unit**

**The British Thermal Unit (B.Th.U.) used by British Engineers is the quantity of Heat which will raise the Temperature of one pound of Water 1 degree Fahrenheit.**

*How many B.Th.U. will raise the temperature of* (a) 50 *lb. of water* 10° *F.?* (b) 90 *lb. of water* 40° *F.?*

If you examine a gas bill you will find that you are charged at the rate of, say, ninepence per *therm* of heat. A therm is 100,000 British thermal units. The gas company has to guarantee that each cubic foot of gas when burnt will produce a certain number of B.Th.U. of heat, usually 500—this is known as the *calorific value* of the gas. The readings of a gas-meter and the working out of a gas bill are shown below.

| | | |
|---|---|---|
| Present reading, | 16,700 | cubic feet |
| Deduct last reading, | 14,300 | ,, ,, |
| Quantity registered, | 2,400 | ,, ,, |

To obtain number of therms (as prescribed by the Gas Regula-

tion Act) multiply the number of cubic feet registered by the calorific value (500) and divide by 100,000, thus :

$$\frac{2400 \times 500}{100{,}000} = 12 \text{ therms.}$$

The account will be shown somewhat as follows :—

| Index of meter, last account | Index of meter, this account | Gas used | | Price per therm | £ | s. | d. |
|---|---|---|---|---|---|---|---|
| | | Cubic feet | Equivalent No. of therms | | | | |
| 14300 | 16700 | 2400 | 12 | 9 | 0 | 9 | 0 |
| | | | | | 0 | 9 | 0 |

## QUESTIONS

**1.** Define " thermal capacity," " specific heat."

**2.** Fill in the gaps in the following table :—

| Substance | Weight. grm. | Specific heat | Thermal capacity |
|---|---|---|---|
| (*a*) Mercury . . | 200 | 0·03 | |
| (*b*) Copper . . | 500 | 0·094 | |
| (*c*) Lead . . . | | 0·033 | 66 cal. |
| (*d*) Turpentine . | | 0·45 | 180 cal. |
| (*e*) Ice . . . | 500 | | 250 cal. |
| (*f*) Aluminium . | 1050 | | 230 cal. |

**3.** Describe how you would find the specific heat of a large lump of iron.

**4.** Calculate the specific heats of the following metals :—

(*a*) Copper, 100 grm. at 100° C. raising 50 grm. of water from 20° to 32·8° C.

(*b*) Aluminium, 20 grm. at 100° C. raising 50 grm. of water from 10° to 16° C.

(c) Lead, 10 lb. at 100° C. raising 20 lb. of water from 15° to 16·5° C.

(d) Tin, 20 lb. at 212° F. raising 20 lb. of water from 40° F. to 50° F.

**5.** How would you find the specific heat of a liquid ? Show how you would calculate the results.

**6.** A large metal vessel contains 612 grm. of water at 15° C. Into it are poured 476 grm. of water at 40° C. and the resulting temperature is 25·4° C. Deduce the thermal capacity of the vessel. If its mass is 445 grm. what is its specific heat ?

**7.** Define (a) the British Thermal Unit, (b) the therm.

**8.** (i) The calorific value of gas is 500 B.Th.U. per cu. ft. How many therms will result from the burning of (a) 1000 cu. ft., (b) 4800 cu. ft. of gas ?

(ii) Find the cost of the above at 10d. per therm.

**9.** Steam is passed into a brass calorimeter (S = 0·096) weighing 1 kilogram and at a temperature of 20° C. If 14·2 grm. of steam condense in warming the calorimeter to 100° C. calculate the latent heat of steam.

**10.** Which would be more effective as a footwarmer, a bottle full of water originally at 100° C. or the same bottle full of lead shot at 100° C. ? Give your reasons in full, making use of the fact that the specific heat of lead is 0·03 and its relative density is 11·3. Assume air temperature is 10° C.

## CHAPTER VIII

# MODES OF TRANSMISSION OF HEAT. APPLICATIONS TO EVERYDAY LIFE

(1) Cut a piece of No. 24 bare copper wire about 4 inches long. Hold one end and place the other in a Bunsen flame. The end you are holding soon becomes too hot to hold in your fingers. Repeat the experiment, using four-inch lengths of iron, eureka, and aluminium wire of the same gauge. *Which of the metals can you hold for the longest time?*

We say that heat is *conducted* along the metals to your hand, and the experiment shows that some metals are better conductors than others. Try the experiment with a rod of glass. You can hold this safely at a very short distance from the end in the flame. Glass is obviously a very poor conductor of heat. Draw up a list of a dozen substances you know which are good conductors of heat and a similar list of bad conductors.

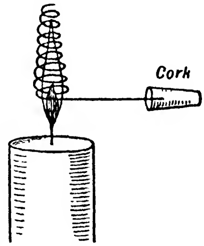



Fig. 48.

(2) Make a close spiral of No. 24 bare copper wire. Insert one end in a cork and hold it as shown in fig. 48, gradually lowering it on to a candle-flame. *What happens, and why?* The candle will not burn if the temperature of the flame is reduced below its *ignition point.* (Refer to Part I, p. 5.) The copper spiral conducts heat from the flame so rapidly that the temperature may be lowered below the ignition point; then the flame goes out.

(3) Repeat the experiments with gauze described in Part I, p. 6. Bring a piece of wire gauze rapidly on to a flame (fig. 49 (*a*)). *When does the flame light above the gauze?* Hold a piece of gauze about half an inch above a Bunsen burner,

turn on the gas and light it above the gauze (fig. 49 (*b*)) *Why does not the gas light below the gauze?* Hold a large sheet of gauze half-way across the Bunsen burner. Light the gas on one side. Explain what happens. Try to put out the flame of a Bunsen burner by drawing a long vertical piece of gauze across it, the lower end of the gauze being in contact with the chimney. With a little practice you will succeed.

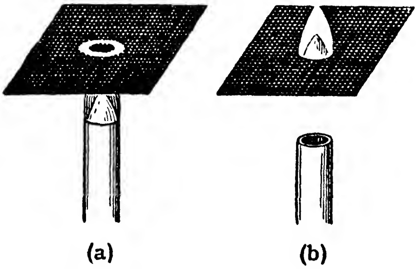



FIG. 49.—Action of gauze on flame

**To compare the Heat-conducting Powers of Iron and Copper**

Melt some paraffin wax in a shallow tin. Dip into it several sheets of white paper. Allow them to drain and cool in the air. Arrange a piece of asbestos tile on a tripod-stand and on it place bars of copper and iron, each a foot long and $\frac{1}{8}$ inch in diameter. Allow about three inches of each to project beyond the tile, allowing one end of each to touch at A (fig. 50).

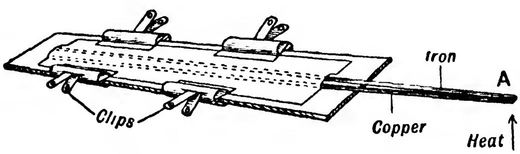



FIG. 50.—Comparing conducting powers of metals for heat

Place a sheet of waxed paper[1] *over* the bars and fasten it securely to the tile with four bull-dog clips so that it is in close contact with the bars. Place a Bunsen burner under end A and heat gently for some minutes. Describe what happens to the waxed paper above each bar and say which of these metals is the better conductor of heat.

[1] Paper soaked in cobalt chloride solution and then dried may be used for this experiment.

**The Conducting Powers of Liquids** (Demonstration experiment)

Support a *thick* copper rod, bent at each end, on two pieces of asbestos board so that the ends dip into thin test-tubes which have a coating of wax on the outside, one containing water and the other mercury (fig. 51). The ends of the rod should dip only about half an inch below the surface. Heat the bar strongly in the middle. Heat is conducted along the bar to each liquid. *The liquids must not be stirred during this experiment.* In time the water boils at the top. After the water has boiled for some time notice how far down the tubes the wax has melted. *Which of these liquids is the better conductor of heat?*

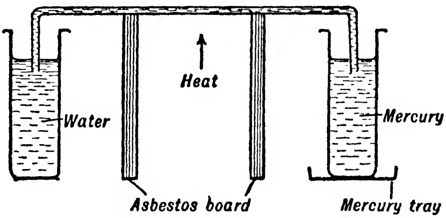


FIG. 51.—Comparing conducting powers of liquids for heat

Place a piece of ice in the bottom of a boiling tube and hold it down by means of wire gauze. Fill up the boiling tube with water and heat this at the top, as shown in fig. 52. The water soon boils at the top. *Does the ice melt appreciably?*

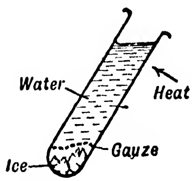


FIG. 52.—Showing that water is a bad conductor of heat

The experiment shows that water is a very bad conductor of heat. But hot water is used extensively for heating purposes. We must now consider how this is possible if water is such a bad conductor of heat.

There is no difficulty in heating water in a kettle, or in a boiler—*but in each of these cases where is the heat applied, above or below?* Clearly the water gets heated by some process other than conduction. This process is called **convection.**

**An Experiment on Convection in Liquids**

Support a round-bottomed flask of water on the ring of a retort stand. Place a glass tube in the water and drop down it

a crystal of the dye magenta (or some potassium permanganate crystals). Remove the tube. Heat the flask below the crystal with a very small flame (fig. 53). This is best done by allowing the gas to burn from a piece of glass tubing pulled out to a jet. Watch what happens to the water and try to draw the appearance of the *convection currents* you observe. It will be evident that the warm water rises, but *why does it rise?* In seeking an explanation consider why a cork held down in water rises when let go. The hot water does not rise merely because it is lighter than the cooler water above, but because it has expanded, and being less dense it is *pushed up* by the surrounding cooler water. Cooler water descends to take the place of the hot water, and so in time all the water is brought to the source of heat.

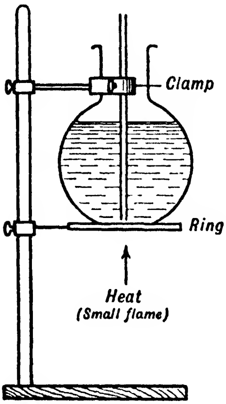



FIG. 53.—An experiment on convection

## Experiments on Convection in Gases

1. Close the windows of an ordinary room and open the door. Hold a lighted candle in the doorway near the floor. Gradually raise it to the top of the doorway, noting the directions in which the flame points as you do this. Draw a diagram to show the direction of the flame (*a*) near the floor, (*b*) near the top of the doorway, (*c*) half-way between. Explain what you observe.

2. Stand a lighted candle in a shallow trough of water. Lower over it a tall glass cylinder, about 2 inches in diameter, (fig. 54). *What happens to the flame?* Explain this. Obtain a long flat piece of cardboard which fits into the cylinder. Repeat the experiment, adjusting the height of the cardboard until the candle burns brightly. Hold a piece of smouldering brown paper at the top of the cardboard. Show the directions of the convection currents in a drawing.

**Ventilation in rooms** containing coal or gas fires is the result of convection. The hot air above the fire expands,

becomes less dense, and is pushed up the chimney by the thrust of the surrounding denser air. Fresh air comes in through doors and windows and through the gaps between the floor-boards.

**Ventilation in mines** was achieved by lighting a fire at the bottom of a shaft. Fresh air entered at the other shafts. You may illustrate this by a model of a wooden or cardboard box, on the top of which two glass or cardboard chimneys are fixed, one side of the box being made of glass (fig. 55). Place a lighted candle below one chimney, close the box, and

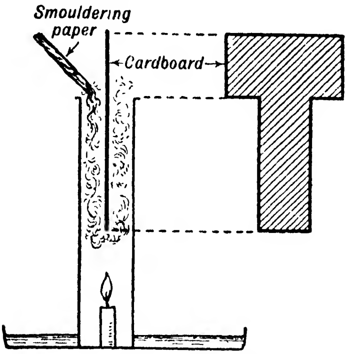



FIG. 54.—Experiment on convection in gases

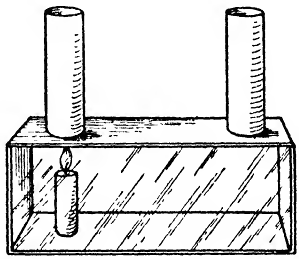


FIG. 55.—To illustrate a method of ventilating a mine

find the direction of the convection currents by means of smouldering brown paper.

## Radiation

*Let us now consider how the sun's heat reaches the earth.* The sun is about 90 million miles away from us. The earth's atmosphere only extends a few miles above its surface. The space between us and the sun for the most part does not contain matter ; it is what we call a vacuum. For the conduction and convection of heat, matter (solid, liquid, or gas) is necessary. Therefore there must be a third process by which heat is transferred from one body to another. This process is called **radiation.** On a sunny day you can bask in the heat of the sun, but when a large cloud passes between you

and the sun there is a distinct drop in temperature. In fact, you may feel quite chilly and long for the cloud to pass. Evidently the heat which reached you from the sun had not appreciably heated the earth's atmosphere through which it passed. Again, if you stand some distance away from a glowing fire you feel the warmth. If you hold a piece of glass, or metal, or wood between your face and the fire much of this heat is cut off. This is very similar to your experience when the cloud passes between you and the sun. **Heat which reaches us from any source without appreciably warming the intervening medium is called radiant heat.**

## Experiments on Radiant Heat

(1) **Absorption**—Soak a piece of drawing-paper in a solution of Cobalt Chloride ("invisible ink") and allow it to dry. Then paint on it a dull black star B, and on the top of this paste a smaller bright star A made of tinfoil (fig. 55 (*a*)). Hold the paper with the painted side a foot or so from a glowing fire so that radiant heat falls strongly upon it. After a few seconds remove the paper and observe the plain side. *What do you notice about the paper under* (a) *the bright star,* (b) *the dull black star,* (c) *the surrounding white? Which of these surfaces is the best absorber of radiant heat?*

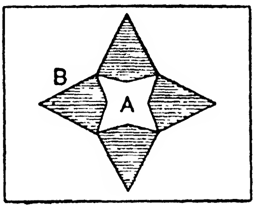



FIG. 55 (*a*).

(2) **Emission**—The "Leslie's cube" L (fig. 55 (*b*)), made of sheet tin, has its sides coated respectively with lampblack, polished black enamel, polished tin, and dull white; and is half full of water kept gently boiling. This maintains each face at the same temperature. The thermopile, an instrument which generates an electric current when heat falls on it, is placed equidistant from each face in turn. The radiant heat emitted by each face in turn generates an electric current in the thermopile, and this passes through a sensitive mirror galvanometer and causes the deflection of a beam of light on the scale. The deflection is proportional to the current, which is proportional to the radiant heat falling on the thermopile.

Some actual results are shown below :

| Surface | Deflection |
|---|---|
| Dull black . . . | 17·2 cm. |
| Polished white . . | 2·0 |
| Bright black. . . | 14·1 |
| Dull white . . . | 16·2 |

The results show that *at* 100° *C. dull surfaces are much the best radiators of heat, and a brightly polished surface is a very*

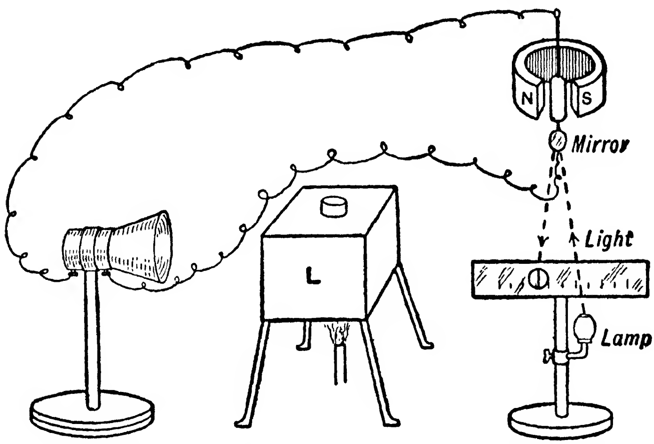



FIG. 55 (*b*).—An experiment on emission of radiant heat

*poor radiator.* At 100° C. dull black is very little better than dull white. Thus, so far as radiation is concerned, hot-water pipes may be painted dull white instead of dull black, but should not be painted with a shiny substance such as Aluminium paint. But it is found that about four-fifths of the heat getting into the air from hot-water pipes does so by convection, and only one-fifth by radiation. So in any case the colour of the paint makes little difference. In fact, the term " radiator " for hot-water heating apparatus is a misnomer.

From the two experiments you found that a dull surface

is a good absorber and also a good radiator of heat, whilst the bright polished surface is a very poor absorber and a poor radiator. In general it is found that **good radiators of heat are also good absorbers.**

(3) **Power to transmit Radiant Heat**—(i) Arrange the thermopile in front of the dull black face of the Leslie's cube, and note the deflection of the light on the scale. Insert a piece of ordinary glass between the thermopile and the cube. Notice the new deflection. Repeat with a piece of clear rock salt instead of the glass.[1] *Which of these substances transmits the radiant heat best ?*

(ii) Hold the thermopile some distance from a glowing fire (or dull red-hot body) and repeat.

(iii) Replace the Leslie's cube by a white-hot radiator of heat, such as an electric radiant, or point the thermopile towards the sun and repeat the experiment.

The experiments clearly show that :

**Glass intercepts nearly all the radiation from a body at 100° C. ; also glass intercepts a large part of the radiation emitted by a red-hot body, but transmits a considerable fraction of the radiant heat from a white-hot body. Rock salt transmits radiant heat from both cool and very hot bodies.**

**The Action of a Greenhouse**—This will be understood after the last experiment. The glass transmits radiant heat from the sun, the white-hot surface of which is at a temperature of about 6000° C. The heat is absorbed by the plants and other objects inside the greenhouse, but their temperature is well below 100° C., so that the radiant heat which they emit cannot pass through the glass. Thus a closed glass-house gets very warm in the day-time. Similarly on a cold night a closed glass-house is easily kept warmed by hot-water pipes, very little radiation from which gets through the glass. The absence of convection currents is probably a very important factor in keeping the glass-house warm.

**A fire screen** makes use of the fact that glass reflects and absorbs a good deal of the radiation from a fire at a dull red-heat.

[1] Call the percentage transmitted by the air 100, and work out the percentages transmitted by the glass and the rock salt.

### The Mechanism of Conduction, Convection, and Radiation

Some time ago there was a fire at a certain school. Before the fire-brigade arrived the boys tried to put out the fire by forming two lines to a pond of water in the garden. One line of boys passed buckets full of water to the house, where they were emptied on to the fire ; the other line passed the empty buckets back again to the pond. We can imagine the boys to represent the molecules of a solid and the buckets of water to represent bundles of heat energy, which the molecules pass along without moving out of place. If each boy had a bucket and walked from the pond to the fire with the bucket full of water, returning with the empty bucket we should have a stream of boys moving from the source of the water to the house and back again. This illustrates the process of convection of heat. Each molecule moves from the source of heat carrying the heat energy with it and, in the case of a liquid, returning again when it has parted with some of this energy and become cooler. When the fire-engine arrives the water is thrown on to the fire from a hose-pipe. This illustrates radiation, radiant energy travelling from the source of heat through space.

To sum up :

(*a*) In conduction we imagine the molecules of the substance to pass on the heat energy without moving out of place. Conduction takes place best in solids.

(*b*) In convection the molecules move about carrying the heat energy with them. Convection can only take place in liquids and gases.

(*c*) In radiation the heat energy passes through space by means of waves which do not heat the space but heat only matter on which they fall.

That heat is a form of energy will be discussed in a later chapter. *You are warned not to look upon heat as a material substance*, as is the water in the illustrations we have just mentioned.

### Some Applications of Conduction, Convection, and Radiation

Examples of the uses of good conductors are legion. The fire-box of a locomotive is made of copper, one of the best conductors ; for stationary boilers iron is used on account

of its cheapness, the large surface making up for its lower conductivity. Copper is used for the " bit " of a soldering iron because of its good conductivity. When the tip is placed on the metal to be soldered heat flows rapidly from the " bit " to the tip and heats the adjacent metal to the necessary temperature. Gases are very poor conductors of heat. The reason why loose fabrics such as wool and cotton are bad conductors is chiefly owing to the air enclosed in the material. If cotton and wool are compressed so as to drive out the air they are very much better conductors of heat. When clothes get sodden with moisture the air is driven out and the conductivity is very greatly increased and may cause a chill to the person wearing them. This is why after a hard game of tennis it is unwise to cool down without putting on extra clothes in the form of a sweater or a coat. If a Scotch shepherd wearing a plaid gets wet and is unable to get home and change his clothes, he rolls his plaid with the wet side next his skin and the dry side out and may then go to sleep in a shelter without taking any harm. The badly-conducting outside material prevents evaporation taking place from the wet clothes underneath. You remember that if evaporation is allowed to take place it is always accompanied by cooling.

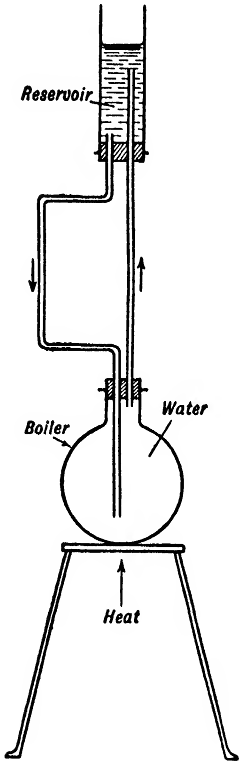


Fig. 56. — Illustrating how a hot-water heating system works

A useful cooker may be made by lining a big box, including the lid, with dry hay. Food is brought to the boil in a pan, which is then placed in the box and the lid put on. Heat escapes so very slowly that the food goes on cooking. The bad conductivity of this " hay-box cooker " is owing to the air trapped by the wisps of hay.

It is important to " lag " the sides and top of a boiler so that as little heat escapes as possible. Special non-conducting materials are used for this purpose.

The working of a hot-water heating system may be understood from the following experiment (fig. 56) :—

The flask is filled with water to which a little phenolpthalein has been added. The tubes and the reservoir are also filled with this. The water is heated and a little strong alkali poured into the reservoir. This colours the phenolpthalein red. Soon the direction of the convection currents is shown

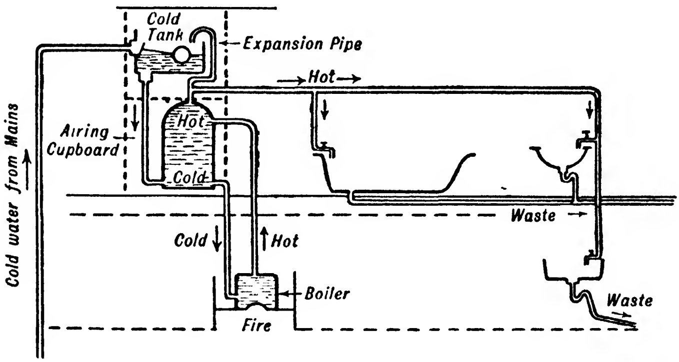



FIG. 57.—A typical hot-water heating system

by the colour travelling round. To destroy the colour after the experiment add a few drops of acid to the water in the tank whilst still hot.

Fig. 57 shows the general arrangement of hot-water apparatus in an ordinary building.

As stated in Part I, p. 100, the best position for the cold-water tank is in the airing cupboard in the bathroom, and not under the roof. When the system is not working the level of the water in the cold tank is the same as in the expansion-pipe. When the system is working the level of water in the expansion-pipe is higher than that in the cold tank *Why is this ?*

So-called " radiators " in a school classroom act mainly by convection. The air in contact with a hot " radiator " is warmed and rises by convection. You have learnt that

radiation takes place best from rough surfaces, especially dull black, but in view of the fact that only 20 per cent. or less of the heat escaping from a hot-water radiator does so by radiation there is little to be gained by painting this dull black. Very little is sacrificed in efficiency and much gained in beauty by choosing some bright colour.

## Ventilation

Fresh air contains 4 parts in 10,000 of carbon dioxide. A human being exhales 0·6 cubic feet of this gas per hour. He also exhales large quantities of water vapour and a

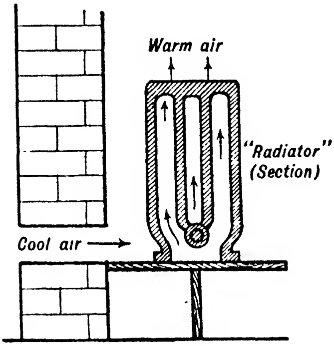



FIG. 58.—A method of ventilation

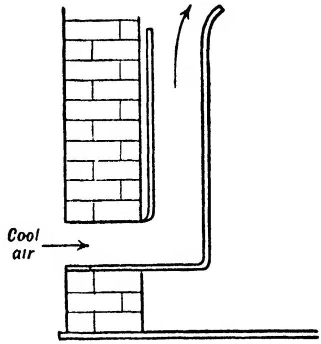



FIG. 59.—Another method of ventilation

larger proportion of nitrogen than he inhales. The air of a crowded room therefore tends to become less and less rich in oxygen and richer in carbon dioxide and water vapour. This results in a stuffy unpleasant atmosphere unless fresh air is constantly admitted. The renewal of the air of a room or building is called ventilation. The temperature of the air of a classroom should be about 65° F. for comfort. The expired air from the lungs is at about 98·4° F. and consequently rises by convection. If the surrounding air is at 63° F. it is estimated that the air expired from the lungs will rise at the speed of about 5 feet per second. For ventilation to take place there should be outlets near the ceiling for the vitiated air. Fresh cool air is usually admitted near the floor, as shown

in fig. 58, but a better plan is to admit it into the room about half-way up the walls. This is often done by some form of ventilator, a type of which is shown in fig. 59.

A coal or a gas fire fitted into a fire-place with a chimney aids ventilation.

The problems arising out of the ventilation of large rooms are not yet satisfactorily solved, and experiments are continually going on to improve present arrangements.

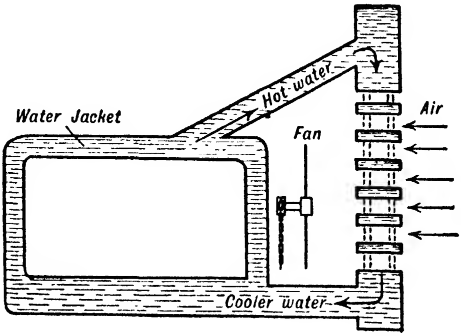



FIG. 60.—Diagrammatic illustration of motor-car " radiator "

The " radiator " of a motor-car (fig. 60), like that of a hot-water system, loses heat mainly by conduction and convection. The engine of a motor-car is surrounded by a water jacket to cool it by removing the waste heat. The water circulates by convection, and in the " radiator " it passes through a large number of thin tubes which present a large surface to the air. A stream of cool air is drawn through these by means of a fan. The hot water enters the " radiator " at the top; after cooling it leaves at the lower end and again enters the jacket surrounding the cylinder. A better name for the " radiator " would be " convector."

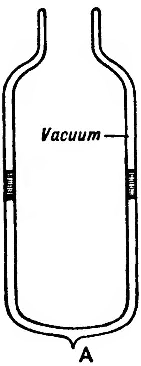



FIG. 61.—A vacuum flask

**The vacuum flask** (fig. 61) was invented by Sir James Dewar in 1892 to store liquid air, which boils at $-180°$ C., and could not be kept for any length of time in an ordinary vessel. The flask is a double-walled glass vessel, exhausted of air and sealed up at A. Before exhausting and sealing up a silvering solution is run through the cavity between the walls, thus leaving silvered surfaces. Three or four small pads of

felt or cork are enclosed round the middle to prevent the glass being shattered by vibration. A hot liquid corked up in the flask loses heat very slowly indeed, for glass is a bad conductor ; convection cannot occur at all, as the cavity contains no air ; the silvered surfaces reflect heat so that the small amount of loss which might occur owing to radiation is reduced to a minimum.

## Atmospheric Convection

**Land and Sea Breezes** (fig. 62)—If you are ever at the seaside during a spell of calm hot weather do not fail to notice the

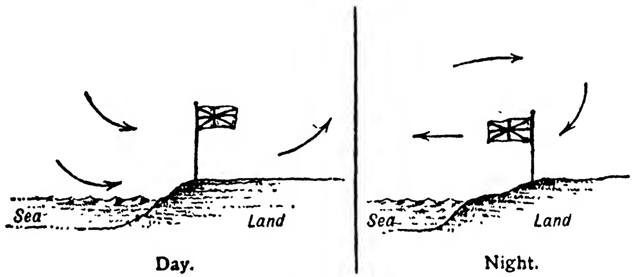



FIG. 62.—Land and sea breezes

direction of the light breeze during the day-time and at night. In the day-time the earth becomes heated to a much higher temperature than the sea, owing to its low specific heat. The air above the earth then becomes hotter than that over the sea, expands, becoming less dense, and is pushed up by cooler air which comes in from the sea, forming a cool sea-breeze. After the sun has set, the land, being a rough surface, cools rapidly by radiation ; the sea cools very little, and eventually the air over the land is cooler than that over the sea. The result is a land-breeze.

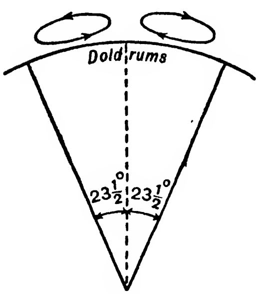



FIG. 63.

The great calm and wind belts of the ocean are due to convection. In the tropics in summer the air over the Equator

rises vertically, causing the belt of calms known as the doldrums (fig. 63). On each side of this belt cooler air rushes in from higher latitudes. If the earth were still these would be north winds in the northern hemisphere and south winds in the southern hemisphere. But the earth is rotating from west to east and in consequence the winds are deflected, becoming the North-East and South-East Trade Winds.

### Ocean Currents

Owing to the water near the Equator being hotter than that near the Poles convection is continually taking place. The denser cold water from the Poles creeps along the ocean-bed towards the Equator, whilst the warmer water travels along the surface from the Equator towards the Poles. The direction taken by the surface-currents is influenced by the direction of the prevailing winds. The Equatorial currents in the Atlantic strike the east coast of America, then they divide, one part flowing southward down the coast of Brazil, the greater part flowing northward round the Gulf of Mexico. This current finally passes out into the North Atlantic.

You should refer to your atlas for diagrams showing these currents.

## QUESTIONS

1. Describe an experiment to show which of two given metals is the better conductor of heat.
2. How would you compare the conducting powers for heat of water and mercury ?
3. Describe experiments to illustrate convection in (*a*) a gas, (*b*) a liquid.
4. Distinguish between conduction, convection, and radiation of heat, giving an example of each.
5. Give one example of the practical use of each of the following: (*a*) a bad conductor, (*b*) a good conductor, (*c*) convection currents in liquid.
6. Describe the action of a hay-box cooker.
7. Make a sketch showing a section of a thermos-flask, and describe how it works.
8. Explain the action of the glass in a greenhouse.

## CHAPTER IX

# HEAT AND ENERGY

**Force and Work**—Whenever you try to move an object you exert a force on it. The earth exerts a force on each object on its surface and this force is called the weight of the object.

If a stone is dropped from a bridge it is this force that causes the stone to gain speed as it drops. For instance, a stone dropping freely from rest near the surface of the earth is found to have the following speeds :—

| | |
|---|---|
| At the start its speed is zero | |
| After one second from rest its velocity is | 32 ft./sec. |
| After two seconds from rest its velocity is | 64 ft./sec. |
| After three seconds from rest its velocity is | 96 ft./sec. |

In these figures the retarding effect due to friction against the air is neglected.

Consider a book at rest on a table. It is said to be in *equilibrium*. As the earth is pulling the book down, the table must be pushing it up with a force equal and opposite to the pull of the earth. These two forces acting on the book balance each other, *i.e.* their *resultant* is zero.

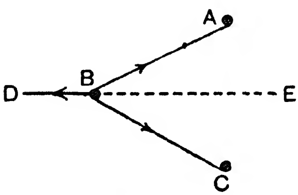


FIG. 64.

Now consider a catapult, a plan of which is shown (fig. 64). The two elastic bands AB and BC exert forces in the directions of the arms on the missile at B. So long as the missile is held stationary the forces due to the elastic are balanced by the force in direction BD. Here we have *three* inclined forces in equilibrium. The resultant of the three forces is zero. When the missile is released it is propelled in the direction BE, opposite to BD. This shows that the resultant of the two forces along AB and BC acts in direction BE, and this force is equal and opposite to the force along BD.

Attach a spring-balance (fig. 65) to a 2 lb. weight on the floor. Watch the indicator as you raise it *slowly and steadily* several feet by means of a rope passing over a pulley. *Does the reading of the indicator alter ?*

Now raise the apparatus rapidly through several feet. This time the reading of the indicator increases during transit, showing that when a body is raised *at an increasing speed it appears to weigh more than when it is at rest.*

You have probably observed a similar effect when in a lift. On starting to travel upwards your feet appear to press more heavily on the floor.

Still holding the weight by the spring-balance, allow it to fall rapidly to the floor. Note what happens to the reading. *Is this what you would expect after the preceding experiment ?*

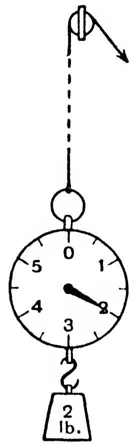



FIG. 65.

When the 2 lb. weight is raised slowly through a height of 5 ft. we say that $2 \times 5 = 10$ ft.-lb. of work are done on it. If a 40-lb. weight was slowly raised through a height of 10 ft., $40 \times 10 = 400$ ft.-lb. of work would be done. **Whenever a force moves a body work is done; the work is measured by the product of the force and the distance.** *The distance must be measured in the direction of the force.*

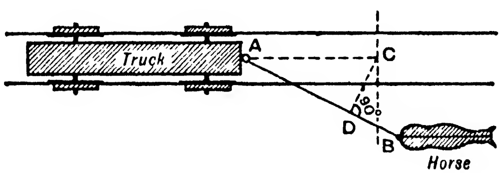



FIG. 66.—Work is measured by the product of force and distance, the distance being measured along the line in which the force acts.

Thus if a horse pulls a truck from A to C (fig. 66) by exerting a steady force along the rope AB (this force may be measured by a spring-balance attached at A or B) the distance to be measured in calculating the work is not AC but AD.

Obviously if the maximum work is required from a given force the horse must walk between the rails so that the direction of the truck is the same as that of the force.

It is interesting to know [1] that it has been estimated that the work done by an average human heart in pumping the blood through the body amounts in twenty-four hours to the work done in lifting 220 tons one foot from the ground.

## Potential and Kinetic Energy

Energy is ability to do work. A stone weighing 2 lb. held 10 feet above the ground is said to possess $2 \times 10 = 20$ ft.-lb. *of potential energy*. This simply means that on account of its *position* it is capable of doing 20 ft.-lb. of work when released.

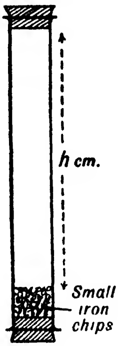



FIG. 67.—Apparatus for showing the production of heat from mechanical energy

As the stone falls it loses this potential energy. Thus when 8 ft. from the ground it still possesses $2 \times 8 = 16$ ft.-lb. of potential energy. What has become of the $20 - 16 = 4$ ft.-lb.? This has been converted into *energy of motion* or **kinetic energy.** When the stone reaches the ground all its potential energy has been converted into kinetic energy. *What happens to this kinetic energy when the stone is brought to rest?* Let us try an experiment to find the answer to this question.

Obtain a glass tube about 70–100 cm. long and 4–6 cm. wide, fitted with corks (fig. 67). Pour into it about 5–10 cm. depth of small dry iron chips. Insert a metre rule and measure the distance $h$ from the top of the chips to the position of the lower edge of the top cork. By means of a thread lower a thermometer reading in 1/10° C. into the chips and roll the tube about until the thermometer is steady. Read and then take out the thermometer. Close the tube and invert it 100 times so that the chips fall altogether a distance of $100h$ cm. Insert the thermometer again and roll the tube for a few minutes until the thermometer is again steady. Note the reading. *What has happened to the thermometer reading?*

[1] *Inventors at Work*, Iles, p. 254.

*What do you conclude has become of the kinetic energy of the iron when brought to rest?*

The experiment shows clearly that heat has been generated by the stoppage of the moving iron. We conclude that **heat is a form of energy.** Let us apply the experiment to calculate how much energy is equivalent to one unit of heat. This is called the **mechanical equivalent of heat.** The results of some actual experiments are given below. You should make calculations from your results in the same way.

**Actual results for the mechanical equivalent of heat by the above experiment:**

Material: Iron chips
Mass $m$ grm.
Specific heat $S = 0{\cdot}11$

| Experiment | 1 | 2 | 3 |
|---|---|---|---|
| Temperatures: | | | |
| Initial (° C.) | 18·0 | 19·1 | 17·5 |
| Final (° C.) | 19·3 | 20·6 | 19·7 |
| Rise ($t$) (° C.) | 1·3 | 1·5 | 2·2 |
| Heat in Calories: | | | |
| $m \times s \times t$ | $m \times 0{\cdot}11 \times 1{\cdot}3$ | $m \times 0{\cdot}11 \times 1{\cdot}5$ | $m \times 0{\cdot}11 \times 2{\cdot}2$ |
| Distance of fall ($h$), cm. | 69·4 | 69·2 | 87·5 |
| No of falls ($n$) | 100 | 100 | 100 |
| Total fall ($nh$) cm. | 6940 | 6920 | 8750 |
| *Energy in grm. cm.:* | | | |
| $mnh$ grm. cm. | $6940m$ | $6920m$ | $8750m$ |
| Mechanical equivalent of heat in | $\dfrac{6940m}{m \times 0{\cdot}11 \times 1{\cdot}3}$ | $\dfrac{6920m}{m \times 0{\cdot}11 \times 1{\cdot}5}$ | $\dfrac{8750m}{m \times 0{\cdot}11 \times 2{\cdot}2}$ |
| grm. cm. per calorie | 48500 | 41800 | 36500 |
| Mean value = 42300 grm. cm. per calorie | | | |

You will notice that the results vary by about 16 per cent. on each side of the mean. The experiment is therefore not an accurate one. To obtain an accurate value for the mechanical equivalent of heat requires more refined apparatus, and

corrections have to be made for various sources of error. A great English scientist named Joule (1818–1889) spent many years in accurate experimental work to obtain the value of the mechanical equivalent of heat. For a full account of his life and work you are referred to *Joule and the Study of Energy*, by Dr Alex. Wood.[1]

Joule measured the work done and the heat produced by forcing water through tubes, by stirring water or mercury by paddles in a special calorimeter, by friction of solids on solids, and by passing an electric current through a wire immersed in a calorimeter, and in other ways. His experiments are remarkable for their accuracy and their variety, and later workers have abundantly confirmed his results.

**The Mechanical Equivalent of Heat is denoted by the letter J after Joule,** and the values now accepted are:

$$\begin{aligned} J &= 778 \text{ ft.-lb. per B.Th.U.} \\ &= 778 \times \tfrac{9}{5} = 1400 \text{ ft.-lb. per lb. degree C.} \\ &= 42{,}800 \text{ grm. cm. per calorie} \\ &= 4{\cdot}2 \times 10^7 \text{ ergs, or 42 million ergs, per calorie} \\ &= 4{\cdot}2 \text{ Joules per calorie.} \end{aligned}$$

[An erg is the work done by a force of 1 dyne in moving 1 cm.

$$1 \text{ dyne} = \tfrac{1}{981} \text{ grm. weight}$$
$$1 \text{ Joule} = 10^7 \text{ (i.e. 10 million) ergs.]}$$

The conversion of kinetic energy into heat is also illustrated in the melting of a bullet when it strikes the target.

## Various Forms of Energy

Rub a pointed stick of hard wood along a groove in a deal board. After a few minutes the deal becomes charred, and if the point of the stick is allowed to touch a small piece of phosphorus this is set on fire.

This experiment illustrates one of the earliest methods of making a fire, by rubbing a stick in a groove until some wood shavings were set alight (fig. 68).

Make a small bow and wrap it round the stick. Press the

[1] Also to *Heat*, by Nightingale.

latter down on to the deal board and work the bow. In a few minutes you may even be able to set alight some sawdust. This illustrates the fire-drill of the American Indians (fig. 69).

The conversion of electric energy into heat occurs in electric-lamps, electric-irons, and radiators.

It is thus seen that **energy may be converted from one form into another.** Scientists have satisfied themselves that **energy is never destroyed. Whenever energy seems to disappear, in reality it has only been converted into another form. This principle is called the Conservation of Energy.**

FIG. 68.—Production of heat by friction

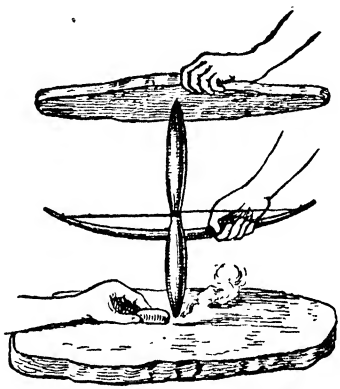


FIG. 69.—A fire drill

## QUESTIONS

1. What is meant by (*a*) "force," (*b*) "work"? How is work measured?
2. Explain (*a*) Potential energy, (*b*) Kinetic energy.
3. State which of the following possesses Kinetic and which Potential energy:—
   (i) The weight used in a clock (*a*) when wound up and at rest; (*b*) when falling.

(ii) The water (*a*) in a mill-dam ; (*b*) when working a waterwheel.

(iii) (*a*) Gunpowder in a cartridge ; (*b*) a bullet in flight.

(iv) A pendulum (*a*) when ready to swing; (*b*) when swinging.

**4.** What is meant by the Mechanical Equivalent of Heat? Describe a simple experiment to determine its value.

**5.** Lumps of (*a*) Iron ($s = 0{\cdot}11$), (*b*) Aluminium ($s = 0{\cdot}21$), (*c*) Lead ($s = 0{\cdot}030$), each weighing 10 lb., are dropped down a well 390 ft. deep. If all the energy were converted into heat how much heat would result in each case and what would be the rise in temperature?

(J = 780 ft.-lb. per B.Th.U.)

**6.** Joule found the value of "J" by taking the temperature of the water at the top and the foot of a high waterfall, using a thermometer which he could read to within 1/200° F.

(*a*) What rise in temperature could be expected in the case of a waterfall 500 ft. high?

(J = 780 ft.-lb. per B.Th.U.)

(*b*) What would be the height of a fall where the temperature above and below differed by 0·5° F.?

## CHAPTER X

# INTRODUCTION TO BIOLOGY: PROPERTIES OF LIVING ORGANISMS

**Biology** is the study of living things or living organisms. An **organism** is a body which is composed of a number of parts or organs. Each of these is concerned in some special work in the life of the organism. Every living organism is either a *Plant* or an *Animal*, and there are *certain signs by which it may be distinguished from a non-living body.* These are as follows :—

(*a*) **A Living Organism has the Power of Movement**—If a living animal is observed it will be noticed that sooner or later it moves of its own accord, although sometimes it moves because some outside influence is acting upon it. Movement of only one or more organs may take place, as when the hand and arm are moved to pick up a book ; or the whole body may move from one place to another, as when one walks across the room. *The movement of the whole body from one place to another is* **locomotion.** Most animals possess this power, although some remain fixed during adult life, *e.g.* Sponges and Acorn Barnacles. Most plants do not possess the power of locomotion, but some small plants can move from place to place by swimming. Slow movements of plant organs are always taking place, *e.g.* buds open, shoots and roots lengthen and push their tips forward.

(*b*) **A Living Organism has the Property of Irritability**—An outside influence may act upon a living organism and cause it to make some response. The response may be a movement, although it need not be so. It may be any kind of activity set up within the organism. Such an influence is called a **stimulus,** and the organism is said to be **irritable** or to **respond to the stimulus.** If a snail be touched it withdraws its body into its shell. If a bright light suddenly flashes before our eyes we blink. Leaves and flowers of a hyacinth grown in

a glass jar in front of a window slowly bend towards the light and the roots bend away from the light. All of these are examples of irritability of living organisms. The response to a stimulus is always of some use or benefit to the organism. Thus the snail may escape injury by shrinking into its shell; and the leaves of the hyacinth bending towards the window receive the light they need for their work of food-making.

(*c*) **A Living Organism has the Power of Respiration**—Throughout life a living organism continually takes in air from which it removes some of the Oxygen. It uses this Oxygen in the process of *respiration* which goes on *in its body*, and it gives out Carbon Dioxide and Water Vapour which have been made in the process of respiration, together with any unused air. The intake and output of gases is called *breathing*, and breathing is the first and last stages of respiration. The essential part of respiration is invisible and takes place within the body. It results in the conversion of Oxygen into Carbon Dioxide (Vol. I, pp. 129–130).

In animals we can usually see the movements by which breathing is carried out, but when no such breathing movements can be seen "internal" respiration is still taking place. In plants no breathing movements can be seen, because there is only a slow passage (*diffusion*) of the gases in and out through a multitude of tiny openings in the skin of certain parts of the plant. Special experiments are needed if we wish to prove that this "breathing" and the internal process of respiration take place in plants.

(*d*) **A Living Organism has the Power of Nutrition** (*i.e.* of nourishing itself)—An animal must feed in order to live, and feeding movements can usually be seen. A plant also feeds, but no feeding movements can be seen, because the food is taken in, either by the roots as a solution of mineral salts obtained from the soil, or by the leaves as Carbon Dioxide. The Carbon Dioxide is either obtained from the air or has been made within the plant by the process of respiration. That plants feed in these ways can be proved by experiments such as those described later. If the food taken in by the living organism is not in soluble form it has to be dissolved before the organism can use it. It is used either for

(*a*) renewing, (*b*) adding to the substance of the body, or (*c*) producing the energy the organism needs for carrying on the activities of its life. In animals the process by which food is changed into suitable soluble forms is called **Digestion,** and a similar process occurs in plants. The soluble bodies formed are **absorbed** by the living material of the organism. They are then further acted upon by it and made into new living material. The process by which an organism makes and adds to itself new living material made from its food is called **Assimilation.** The processes of feeding, digestion, absorption, and assimilation together make up the process of **Nutrition.**

(*e*) **A Living Organism has the Power of Growth**—As long as an organism lives its activities are causing its living material to wear out and die, and if the organism is to go on living this dying material must be replaced by new living matter. This is the chief use of assimilated material, and if any of it is left over it is added to the body of the organism, which therefore increases in size and weight. This renewal and increase is **growth.** If non-living bodies are worn away they cannot replace their lost material, and although they can be made to increase in size and weight they do not grow. A crystal of alum placed in a saturated solution of a suitable salt increases in size and weight because layers of the salt are deposited all over the surface of the crystal. This added salt has not been changed into a new substance, nor does it enter into or become a part of the crystal. No growth has taken place.

(*f*) **A Living Organism has the Power of Excretion**—We have said that the activity of a living organism causes it to produce waste material, which might be harmful to the organism. Harm is prevented by one of two means. Either the waste material is changed by the organism into some harmless form of matter and allowed to remain in the body, or it is passed out from the body. Plants are less active than animals, and so make less waste matter, and this is usually changed into harmless substances which collect in the plant. These may be in the form of tiny granules. Animals have special organs by which the waste matter is collected and then passed out from the body. These are **excretory organs,** and

the process is **excretion.** Waste products are excreted in various ways by various organs. Carbon Dioxide and water are got rid of (*a*) by the lungs when we breathe out, (*b*) by the skin in perspiration, (*c*) by the kidneys, together with another important waste product urea, as urine. Plants have no excretory organs.

(*g*) **A Living Organism has the Power of Reproduction**—The power of producing new living organisms is possessed by all living organisms, and **it is the most striking and important property by which they are distinguished from all non-living bodies.** The simplest form of reproduction is seen in some of the smallest and simplest animals and plants, in which the body of the organism divides into two equal parts each of which then grows and becomes like the original (parent) organism. In most animals and plants the offspring is not only smaller than the parent, but it is different in structure, and it goes through changes of form and structure (which process is **development**), as well as changes of size (**growth**), before it is " grown up." You have seen during early spring masses of Frog's spawn. These consist of clear jelly, containing tiny specks (eggs). From each egg a tiny tadpole hatches out. This tadpole is different, both inside and outside, from a Frog. It grows, and its form and structure change, *i.e.* it develops. Soon it grows limbs, loses its tail, and becomes a small frog. This small frog then grows until it reaches full size. In some animals, *e.g.* Rabbit and Man, the young when born are like the parent in form and structure, but smaller in size. They have undergone development from the egg before birth, and so we do not see them develop, but we can watch them grow.

## QUESTIONS

1. Give an account of three characters by which a living organism may be distinguished from a non-living body.
2. What is meant by the terms Irritability, Respiration, Nutrition, Reproduction ? Give examples of each.
3. Give a list of the chief activities of the living organism and describe any two of these activities.
4. Give an account of the processes of Assimilation and Excretion. Of what value are they to the living organism ?

# CHAPTER XI

## TWO SIMPLE LIVING ORGANISMS. AMŒBA (AN ANIMAL) AND CHLAMYDOMONAS (A PLANT)

**Amœba**—Living organisms have the peculiar properties we have just described, because the body of every living organism is mainly composed of a living substance called **protoplasm** and of substances made by it. Living protoplasm

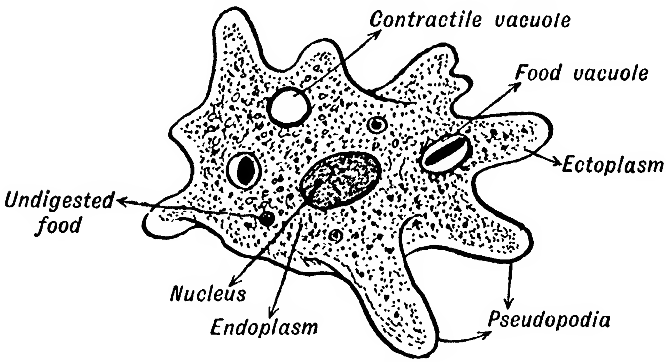



FIG. 70.—Amœba

has all the properties possessed by living organisms. No non-living matter contains protoplasm, and this is why no non-living body is like a living organism. It may surprise you to learn that this substance from which all living organisms are made is a **living liquid** very similar to the jelly-like colourless " white " of a raw egg. Like oily liquids, when placed in water it forms tiny round drops. The body of Amœba—one of the simplest and smallest of animals—is merely one such tiny globule of protoplasm.

**Amœba** (fig. 70) is found on the mud of freshwater ponds and sluggish streams, and is a tiny greyish-white speck just

visible to the naked eye—being less than 1/100 of an inch in diameter. One kind of Amœba, if taken in with foul drinking-water, lives in the bowels of man, and causes a form of the disease called dysentery. Examined under the microscope the animal is seen to be composed of a thin outer layer of clear protoplasm and of inner protoplasm which contains many tiny granules. The clear outer protoplasm is called **ectoplasm,** and the inner granular protoplasm is **endoplasm.** Near the middle of the animal is a rounded mass of denser protoplasm called the **nucleus.**

**How Amœba Moves**—Unlike a drop of oil floating in water, Amœba is able to change its shape. It pushes out blunt, unbranched, finger-like projections of its protoplasm, while at other points the protoplasm is drawn inwards. The projections are **pseudopodia** (false feet). The animal moves slowly along with a sort of "rolling over" motion as a result of this pushing-out and pulling-in of the protoplasm.

**Amœba is Irritable**—If a pseudopodium meets any object unsuitable for food it creeps, or perhaps we should say flows, past it. If a little strong acid or alkali be added to the drop of water in which an Amœba is being examined under the microscope the animal glides rapidly away to avoid the diffusing irritant. These actions show that Amœba is irritable.

**How Amœba Feeds and is Nourished**—If a pseudopodium touches a small object suitable for food (*e.g.* one of the very tiny green or yellowish plants on which the animal feeds), the pseudopodium flows round and encloses the food body, which is soon seen, surrounded by a thin film of water taken in with it, lying within the endoplasm. This is **ingestion.** The space in which the food body lies is a **food vacuole.** The little green food plant is slowly dissolved (digested) by the action of an acid liquid made by the surrounding endoplasm. This liquid oozes into the food vacuole which is a temporary digestive organ. The liquid contents of the food vacuole become alkaline, and are absorbed by the endoplasm, and the unused parts of the food remain in the vacuole. The Amœba slowly flows on, and at last leaves the remaining undigested substance behind. This process of expelling the undigested remains of the food body is **egestion.**

**How Amœba Grows**—The absorbed liquid made from the food is assimilated by the protoplasm, *i.e.* it is made into new protoplasm which becomes a part of the body of the animal and by this means the Amœba grows.

**How Amœba Respires**—No breathing movements take place. The water in which the Amœba lives contains dissolved Oxygen, and the animal absorbs supplies of this gas at all parts of its surface. This process is the first or external stage of respiration. The Oxygen oxidises some of the protoplasm and so produces the energy which the animal needs in order to carry on the activities of its life. This oxidation of the protoplasm results in its being broken down into a number of non-living waste substances of which the chief are *Carbon Dioxide, water,* and a nitrogen-containing body called *urea.* The oxidation of protoplasm to produce energy and these waste bodies is *internal or "tissue" respiration,* and it *goes on in all parts of the body of every living organism. All living organisms must respire in order to live.*

**How Amœba Excretes Waste Matter**—The waste Carbon Dioxide is given out into the surrounding water from all parts of the surface of the animal. In the endoplasm just below the surface of the animal there is a clear round space which may be seen alternately to become larger and suddenly to contract and disappear and slowly to increase again. This is the **contractile vacuole.** Into it drain the water and dissolved urea, which are forced through the protoplasm into the water outside every time the vacuole contracts. This process is *excretion,* and the *contractile vacuole is an excretory organ.*[1]

**How Amœba Reproduces** (fig. 71)—After a time a full-grown Amœba produces young Amœbæ. The nucleus first divides into two equal daughter nuclei which move apart in the endoplasm. The protoplasm between them narrows and the animal is "pinched" into two halves each containing one daughter nucleus. Each half is a young Amœba, and these move apart and each grows into an adult animal. This simple process of reproduction by division into two equal parts is **simple** or **binary fission.**

[1] The contractile vacuole also regulates the osmotic pressure within the cell. See footnote on p. 104.

In some circumstances (*e.g.* long periods of cold or drought) the Amœba passes into a *resting state*, and because it cannot obtain any food it lives on its own protoplasm. It must therefore be careful not to expend much energy. It becomes rounded and makes for itself a tough case called a **cyst** (fig. 71 (*c*)), within which it rests. When circumstances again become favourable the cyst bursts, the animal flows away from it and resumes its active life. Sometimes during encystment the

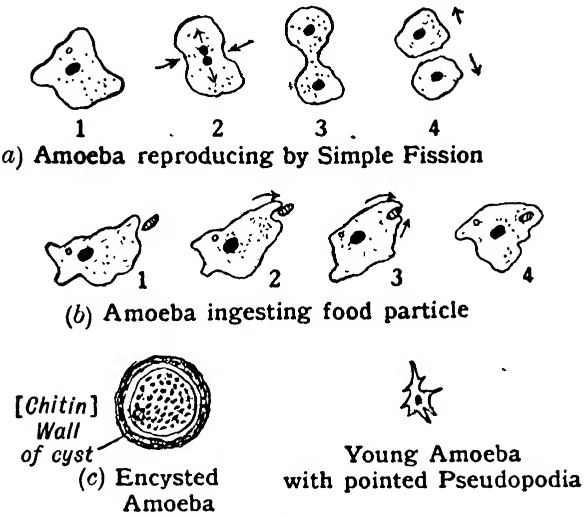



FIG. 71

nucleus of the Amœba divides into a large number of parts, around each of which some of the protoplasm collects. Thus a large number of small Amœbæ are formed, the cyst bursts, and they escape. These little Amœbæ, whose pseudopodia at first are rather pointed, are called **spores.** They flow away and grow into adult Amœba. This process of reproduction is **multiple fission** or **spore formation.** Thus this simple and tiny animal, Amœba, carries out all the activities that are characteristic of a living organism.

Its body is not divided into a number of organs such as we find in our own bodies, *e.g.* lungs or breathing organs, legs

or organs of locomotion, eyes or organs of vision, etc., but *most of the work of the Amœba can be performed by any part of its body.* Thus any part of the protoplasm may become a pseudopodium or organ of locomotion, any part can be a digestive organ (food vacuole), and so on. The only part of the Amœba which is a separate structure is the *Nucleus*, and we can hardly call this an organ, as it has no special work to do. *The Nucleus really controls* **all** *the life of the organism*; indeed, we find that no protoplasm can live for very long unless there is a nucleus present in it.[1]

## Practical Work

**To obtain Amœbæ**—The best time for obtaining these is during the early summer. With a wide test-tube skim off the surface mud from the bottom of a slow-moving stream. Place the muddy water to settle in a shallow dish for twenty-four hours. With a small pipette take off small quantities of the surface of the film of sediment and examine these in a watch-glass on a piece of black paper. If Amœbæ are present they will be seen as tiny greyish-white specks. (It is generally best, however, to obtain some Amœbæ from a dealer.) Place the Amœbæ in a shallow glass vessel (*e.g.* an ox-tongue dish) containing clean rain-water (tap-water is usually too alkaline). Place in a cool shaded place at about 45° to 50° F. To the water add a few wheat grains which have been boiled in water for about five minutes. A culture of Amœbæ should then be obtained. The animals are in active growth in early summer, undergo fission July to November, encyst during the winter, and young Amœbæ are set free in early spring.

[1] The blood of *Mammals* (*e.g.* Man, Rabbit) contains floating in its liquid a multitude of tiny masses of protoplasm none of which have a nucleus. They are called *red corpuscles* because they contain red colouring matter (*hæmoglobin*). They are so numerous that they cause the blood to be red. Their work is to *carry Oxygen from the lungs to all parts of the body, and to carry Carbon Dioxide from all parts of the body to the lungs.* They are formed from cells which have nuclei, from which they are "pinched off," but *they have not a long life.* They soon die, and the animal gets rid of their dead bodies and makes new red corpuscles to replace them. However, we shall give a full account of these red corpuscles and their work in a later chapter.

### Experiments with Amœbæ

(1) **To Study the Response of Amœbæ to Light**—Take a dish containing Amœbæ and shade half the dish with a piece of black paper. Observe the slow movement of the Amœbæ. *Do they collect in the shaded or the unshaded part of the dish? Do you conclude that Amœbæ are sensitive, or not, to light?*

(2) **To Study the Structure and Movement of Amœba**—Mount some Amœbæ in a drop of distilled water on a glass slide. Cover with a glass slip and examine under a high power [1] of the microscope. Make out as much as possible of the structure of the animal, and draw it.

Make a series of drawings at intervals of, say, one minute to show the changes of shape undergone by the animal.

If it is desired to kill Amœbæ for examination this may be done by drawing (by means of filter-paper) a drop or two of Osmic Acid (2 per cent. solution in water) under the cover-slip

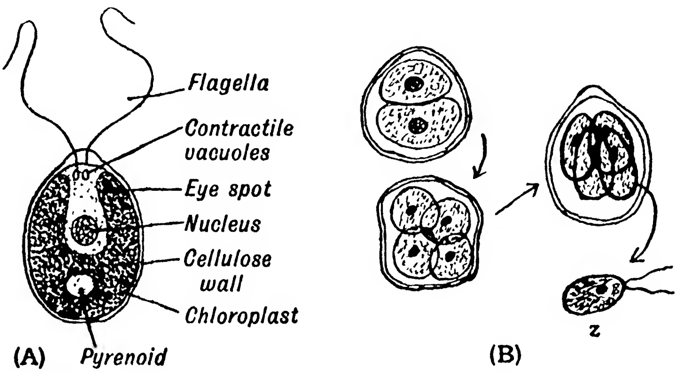
## Chlamydomonas (fig. 72)

We often notice that the water in shallow pools and water-butts has a green colour, and if we examine a drop of such water under the microscope we find in it many very minute oval green bodies which dart rapidly to and fro. Each of these is a *Chlamydomonas plant.* The body of the organism is a tiny mass of protoplasm about 1/1250 in. in diameter. On careful examination it is found that it is enclosed by a thin colourless wall which gives the plant its clear oval outline. The wall is made of a non-living substance called **cellulose,** and has been secreted by the protoplasm. From the pointed front end of the plant two thin threads of protoplasm project into the water. Each is about twice as long as the body of the plant, and is constantly moving with a lashing motion. Hence it is called a **flagellum** (whip) (plural—flagella). The protoplasm consists of two distinct parts, a small central colourless mass and a deep cup-shaped green mass which encloses it. This green protoplasm is the **chloroplast,** and its colour is due to the presence of a green

[1] $\frac{1}{3}$ inch objective for movements, $\frac{1}{6}$ inch for structure.

colouring matter called **chlorophyll** (which colours the green parts of all plants).

In the colourless protoplasm lies a spherical **Nucleus,** and in the chloroplast a large colourless oval body called the **pyrenoid.** In the colourless protoplasm just below the bases of the flagella are a pair of very small **contractile vacuoles,** and close to these a tiny red speck called the **eye spot.**




Adult

Asexual reproduction by formation of spores (zoospores)

FIG. 72.—Chlamydomonas

**How Chlamydomonas Moves**—The lashing movements of the flagella draw the plant along, causing it to dart through the water, turning round with a corkscrew movement as it goes. The flagella are therefore organs of locomotion.

**Chlamydomonas is Irritable**—The plant moves towards light of medium strength, but if the light becomes very bright it moves away from it. This is probably because the eye spot is sensitive to light and somehow causes the plant to respond accordingly.

**How Chlamydomonas Respires**—Like Amœba it takes in dissolved Oxygen from the water around it at all parts of its surface. Waste Carbon Dioxide is given out. We shall learn later that, like all green plants, Chlamydomonas gives off Carbon Dioxide only in the dark. In the light it uses the

Carbon Dioxide which has been formed as a result of respiration (which is **always** going on) as food.

**How Chlamydomonas Feeds and is Nourished** (*i.e.* its mode of **Nutrition**)—We find a difference between the feeding of Chlamydomonas and that of Amœba. The little plant cannot ingest solid food because solid bodies cannot pass through the cellulose wall. Hence the food of Chlamydomonas must consist of gases such as Carbon Dioxide and of soluble mineral salts dissolved in the water. These diffuse into the protoplasm and are made by it into food, chiefly starch—the work being done by the chlorophyll in the chloroplast. The pyrenoid probably takes part in this process. Other substances also are made from the mineral salts by the activity of the protoplasm.

**How Chlamydomonas Grows**—Like all living organisms the plant absorbs the food and assimilates it; so making new protoplasm, and thus it grows.

**How Chlamydomonas Excretes**—As in the case of Amœba excretion is effected by the diffusion of waste matter into the two contractile vacuoles from the surrounding protoplasm, and the liquid is ejected by the contraction of the vacuoles, one of which contracts as the other expands. The contractile vacuoles are therefore excretory organs.[1]

**How Chlamydomonas Reproduces**—The more common mode of reproduction is like that of Amœba. The plant comes to rest, draws in its flagella, the nucleus, and then the protoplasm divide, and each half again divides so that four young plants are formed (see fig. 72, B). A cellulose wall is secreted around each and their paired flagella appear. The wall of the parent plant bursts, and the little plants—each of which is called a **zoospore**—swim away. They quickly grow into adult Chlamydomonas plants. This method of reproduction is **asexual reproduction.**

As in Amœba, another mode of reproduction occurs during cold or drought. Repeated division of a resting Chlamydomonas takes place, the nucleus and protoplasm undergoing

[1] Contractile vacuoles also regulate the osmotic pressure within the cell (as in Amœba). This force enables the plant to absorb dissolved substances from the water, and it retains them—if needed—when it expels fluid into the vacuole.

repeated divisions until usually sixty-four small organisms result, each with a nucleus *but no cellulose wall.* Each is called a *Gamete.* The wall of the parent plant bursts, and the little naked gametes escape, their flagella appear and they swim about. Since many Chlamydomonas plants are dividing at the same time, the water contains swarms of the little naked gametes. They come together in pairs at their pointed ends, and the protoplasm and nuclei of each pair fuse so that each pair forms a single mass of protoplasm with a single nucleus. The new organism is called a *Zygospore.* The process is **sexual reproduction.** As the little swimming gametes have mingled before fusion it will naturally happen that the fusing gametes in most pairs come from different Chlamydomonas plants. There may be advantage or disadvantage in this mixture of the protoplasm of two different plants in the body of each zygospore. If both plants were strong and healthy the resulting zygospore will be doubly so. On the other hand, the zygospore formed by the fusion of protoplasm from two unhealthy or weak plants will be very unhealthy and weak, and may die. The admixture of protoplasm at least ensures the production of a large number of very strong and healthy new organisms.

The new organism (zygospore) is spherical, and it develops a thick cellulose wall within which it rests until the hard times are over. When conditions improve the wall of the zygospore bursts, the contents escape, become oval, secrete a cellulose wall, put out flagella, and grow into an adult Chlamydomonas plant.

**How Chlamydomonas differs from most simple Green Plants** —If a large number of other small green plants be examined it is found that while they agree with Chlamydomonas in possessing protoplasmic bodies with a nucleus, chlorophyll, and pyrenoid, and in being enclosed in a cellulose wall, they differ from it in having no flagella, no contractile vacuoles, and no eye spot. Hence they do not swim, but merely float or rest on damp bodies such as tree trunks, and wooden palings, *i.e.* they have no power of locomotion. Since they have no contractile vacuoles they have no excretory organs, and any waste products other than Carbon Dioxide and water collect

in their protoplasm as minute solid granules, which do no harm to the plant because they are insoluble.

The possession of organs of locomotion and excretion makes Chlamydomonas more like an animal than are most other green plants. Its ability to feed on Carbon Dioxide and mineral salts in solution, and its possession of a cellulose wall, cause it to be classed as a Plant. No animal possesses either of these two characteristics.

Some tiny *animals* closely related to Amœba have their protoplasm enclosed in a shell or wall secreted by the organism, but this wall is *never* composed of *cellulose*. It may be of **chitin** (a horny substance), or it may be calcareous or siliceous, and in all cases it is perforated by one or more openings from which pseudopodia or filaments of protoplasm protrude and the animal can obtain and ingest solid food.

## Practical Work

### Experiments with Chlamydomonas

(1) **To show the Action of Iodine upon Starch**—Take a clean test-tube about half full of distilled water. Add a few starch grains. Boil. Add more water or starch as needed until a thin, clear, opalescent solution is obtained. Allow this to cool. Add a few drops of iodine solution. (Iodine dissolved in alcohol.) A deep blue colouration is produced.

(2) **To obtain, and note the Structure of Chlamydomonas**[1] —Obtain some water from a shallow pool or water-butt. Note its green colour. Mount a drop on a glass slide. Cover with a cover-slip and examine for Chlamydomonas, using a high power of the microscope (at least × 400). The plants appear as small oval green masses. Unless a very good micro-

[1] If *Chlamydomonas* cannot be obtained examine *Pleurococcus*, a minute spherical green plant with a cellulose wall, nucleus, and chlorophyll, but no contractile vacuole, eye spot, flagella, or pyrenoid. It is found in the green powder on the windward side of tree trunks, wooden palings, etc. The plants are often in groups of four, each plant then occupying a quadrant of a sphere. It does not move, but its feeding and "breathing" are like those of Chlamydomonas. It reproduces by dividing into first two and then four small spherical plants, each with its own cellulose wall. It is, in fact, *a more typical plant* than Chlamydomonas because it lacks locomotor and excretory organs.

scope and very efficient lighting are available it will be impossible to see the flagella,[1] eye spot, and contractile vacuoles. Drawings should be made.

(3) **To show that the Protoplasm of Chlamydomonas contains Starch**—By means of a piece of filter-paper draw a drop of iodine solution into the water under the cover-slip. The plants change colour, becoming a brownish or bluish black. This shows the presence of starch in the protoplasm. The starch should give a distinct blue colour with the iodine, but this clear blue tint is usually obscured by the green colour due to the chlorophyll.

## QUESTIONS

**1.** Where is Amœba found? Describe its structure.

**2.** How does Amœba reproduce itself?

**3.** Give an account of Movement, Respiration, Feeding, and Excretion of Amœba.

**4.** Where is Chlamydomonas found and what is its structure?

**5.** How does Chlamydomonas feed, respire, and grow?

**6.** Give an account of the reproduction of Chlamydomonas.

**7.** How do the differences of structure of Amœba and Chlamydomonas affect their food and feeding?

---

[1] Dark ground illumination is often very useful in order to see flagella.

## CHAPTER XII

## THE CELL. TISSUES. TWO SIMPLE MULTICELLULAR ORGANISMS: HYDRA (AN ANIMAL), SPIROGYRA (A GREEN PLANT); AND THE SHEPHERD'S PURSE (A COMPLEX MULTICELLULAR GREEN PLANT)

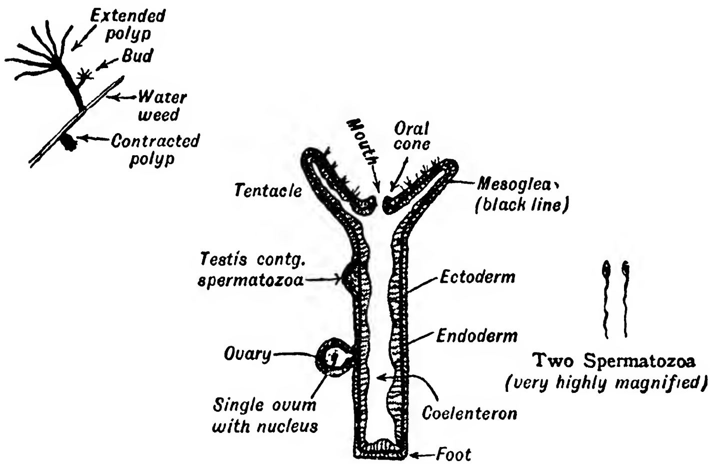
**The Cell is the Unit of Living Matter**—A small mass of protoplasm, with nucleus and other protoplasmic contents, and with or without a non-living cell-wall—such as constitutes the body of Amœba or Chlamydomonas—is called a **cell.** An organism is **unicellular** when its body is composed of a single cell, and **multicellular** when it comprises more than one cell. In most multicellular organisms a large number of cells are found, and these are of many different kinds, differing in their shape and in the nature of their protoplasm. Different kinds of cells perform different activities in the life of the organism for which they are specially suited owing to their particular shape and structure. They have given up some of the many activities carried on by the single cell of a unicellular organism, and have become able to perform more efficiently those that they still do. Such cells are called **fixed or tissue cells.** The life of the cells of a particular tissue is largely dependent upon the activities of cells of other tissues. They soon die if separated from the body of the organism, because they are not self-supporting units like unicellular organisms. In the organs of a multicellular organism cells of similar structure all doing the same work are found collected in tracts or masses. Such a collection of cells is a **tissue.** These cells may be set closely side by side, or they may be more or less separated by a ground substance made by them.

Thus *an Organism is composed of Organs, an Organ is composed*

*of Tissues,* and *a Tissue is composed of Cells* and perhaps some non-living matter secreted by the cells.

Two simple multicellular organisms will next be studied. These are *Hydra,* which is an animal, and *Spirogyra,* which is a green plant. Like most simple living organisms both of them live in water.

**Hydra (the Freshwater Polyp)**—Hydra (fig. 73) may be found attached to water weeds and stones in ponds, wet




Diagrammatic longitudinal section of Polyp

FIG. 73.—Hydra

ditches, and clear streams. It has a thread-like body about $\frac{1}{3}$ in. in length attached to the supporting object by one end (the foot). The free end of the body bears a ring of 6 or 8 tentacles slightly shorter than the body of the polyp.

Sometimes Hydra is found contracted into a short oval mass with the tentacles appearing as tiny knobs projecting from its surface. Three species of Hydra are common. These are coloured respectively green, brown, and greyish-white.

**Examine Hydra and note its Form and Structure**—In a drop of water on a glass slide place two short pieces of pond weed

parallel and about ½ in. apart. With a pipette transfer a Hydra to the water and cover with a glass cover-slip. The weed will prevent the slip pressing on the polyp. When the Hydra has fully expanded make a drawing of it under a hand-lens or very low power of the microscope (× about 5–10). The body of the polyp is a narrow tube closed at the

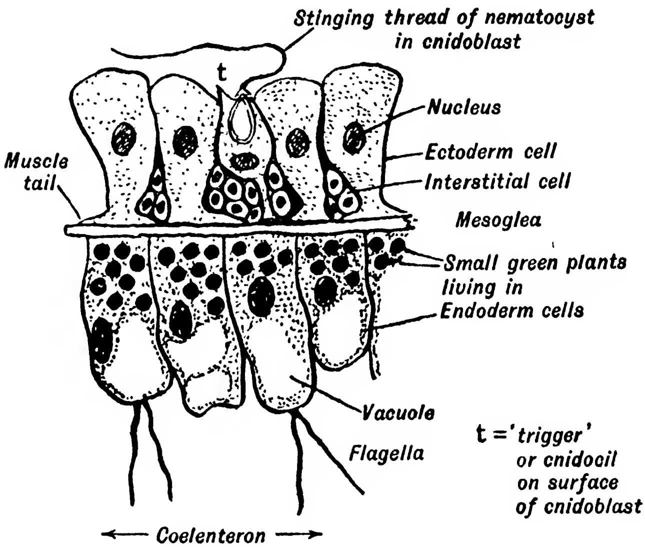



FIG. 74.—Part of body wall of Hydra (highly magnified)

base (foot) and having a small open mouth at the apex of a low cone (oral cone or hypostome) at its free end. The ring of 6 or 8 long slender tentacles springs from the base of the cone. The mouth opens into the long tubular "body and digestive" cavity or **cœlenteron,** which extends the whole length of the animal and is prolonged to the free ends of the tentacles.

**Examine the Minute Structure of the Polyp** (fig. 74) using a magnification of about ×25.

The body-wall consists of two layers of cells, between which is a thin layer of clear gelatinous material. The outer layer

of cells is the **ectoderm,** the inner layer is the **endoderm,** and the non-cellular middle portion is the middle lamella or **mesoglea.** The **ectoderm** consists of several kinds of cells.

(1) The main ectoderm layer consists of large, roughly conical cells, each having a central oval nucleus and granular protoplasm. The narrow inner end of base of each cell is prolonged into one or more contractile threads called **muscle-tails,** which lie along the mesoglea.

(2) The spaces between the bases of these cells are occupied by a number of small oval nucleated cells (**interstitial cells**).

(3) Here and there the large ectoderm cells have embedded among them a small pear-shaped nucleated cell (**cnidoblast**), which is hollowed out inside, and in the cavity of which lies a stinging cell **(nematocyst).** This consists of a little sac containing poisonous liquid, and part of the wall of the nematocyst is prolonged into a long hollow stinging thread, which is tucked in and lies coiled up in the liquid. From the surface of the cnidoblast protrudes a short bristle or "trigger" **(cnidocil).** When a small animal touches this "trigger" the stimulus causes the cnidoblast to contract. This squeezes the nematocyst, and the stinging thread is shot out. If the thread transfixes the animal, the poisonous liquid is forced into its body and paralyses it.

(4) Among the interstitial cells are some small cells with fine branches of protoplasm forming a network of threads. These are supposed to be *nerve cells.*

The **mesoglea** is a thin structureless sheet of clear gelatinous non-living matter secreted by the cells of the body-wall.

The **endoderm** is a single layer of tall cylindrical cells, each with a large nucleus and vacuoles in its protoplasm. The bases of the cells are prolonged into *muscle-tails* on the mesoglea, and the free ends of the cells may bear *pseudopodia* or *flagella* projecting into the cœlenteron.

**How Hydra Moves**—The large cells of the ectoderm are contractile, and the pull of their "muscle-tails" on the mesoglea transmits the force to other parts of the body, and so enables the animal to execute various movements. Its body and tentacles are continually *contracting* and *lengthening* and *swaying to and fro.* In addition, the contractions and

expansions of the foot enable the animal to move slowly along with a *gliding* movement. It can also *swim* by means of movements of the tentacles. It has two other forms of locomotion (fig. 75 (*a*) (*b*)). One side of its body contracts and the other expands, and the animal bends over until its tentacles touch the " ground " near its foot. The foot may then release its hold and be drawn forward and placed on the ground closer to the tentacles, where it holds fast, the tentacles release their hold, and the animal straightens out. By repeating this process the animal moves onwards with a " *looping* " motion. The other mode of locomotion is by " *somersaulting.*" The animal bends sideways until its tentacles obtain a grip of the " ground." The foot then releases its hold and the animal straightens with its foot uppermost and " stands on its tentacles." The foot continues its swing and completes a semicircle, obtains a grip on the ground, and the animal again assumes the upright position, thus having moved forward.

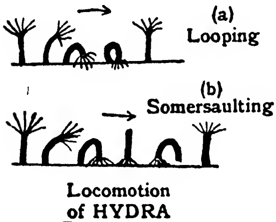



FIG. 75 (*a*) (*b*).

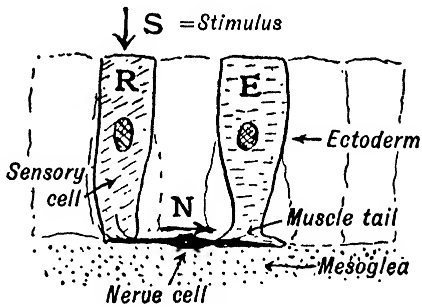



FIG. 75 (*c*).—Simple mechanism for producing *reflex action* (*e.g.* in Hydra)

A sensitive or sensory cell receives stimulus (S). The receiving cell is called a receptor (R). A nerve cell (N) carries a message (impulse) from R to a neighbouring contractile cell of the ectoderm. This cell responds by contracting by means of its " muscle tail." The cell which effects the contraction producing movement is an effector (E).

**Hydra is Irritable**—This is shown in many ways. If the polyp be touched, its tentacles and body contract (fig. 75 (*c*)). If the " trigger " of a cnidoblast be touched, the stinging thread is shot out. The pseudopodia of the endoderm cells

can ingest solid particles, and are able to distinguish and reject those which are unfit for food. The polyp responds to changes of illumination, moving away from a region of very dull or very bright light.

**How Hydra Feeds and Grows**—Hydra feeds on small water animals, especially *water-fleas*. The waving tentacles catch these by means of the stinging threads of their nematocysts and the prey is paralysed by the stinging fluid. The tentacles carry the food to the mouth, and it is drawn into the **cœlenteron** with a water current set up by the lashing flagella of the endoderm cells. The food may be ingested by the pseudopodia and digested within the endoderm cells by a juice (ferment) secreted by their protoplasm. Or digestion of food may take place in the cœlenteron, into which certain narrow vase-shaped cells of the endoderm pour a digestive fluid. The dissolved food is then absorbed by the endoderm cells. The soluble products diffuse throughout the body-tissues and are assimilated. The assimilated matter either replaces worn-out protoplasm or is used to form new protoplasm, and growth results.

**How Hydra Respires and Excretes**—There are no special organs of respiration, nor are any breathing movements seen. Dissolved Oxygen diffuses from the water into the tissues of the animal at all parts of its surface, and internal respiration takes place. The Carbon Dioxide, water, and other waste products produced by the respiration (oxidation of protoplasm) then diffuse out through tissues into the water at all parts of the body-surface. There are no special organs of excretion.

**How Hydra Reproduces**—Hydra reproduces both *Asexually* by budding and *Sexually* by the fusion (conjugation) of a pair of gametes.

(*a*) **Asexual Reproduction by Budding**—When circumstances are favourable, buds form on the sides of the polyp. A bud is produced as follows :—A group of ectoderm cells multiply and form a bulge. New endoderm cells also form and lie in the centre of the bulge, and a solid cylinder of cells is produced which projects from the side of the polyp. A cavity appears among the endoderm cells of the cylinder

and is a cœlenteron continuous with that of the parent polyp. Tentacles grow out from the bud, which now appears as a young Hydra attached to the side of the body of the parent. After some time the young Hydra " pinches off," swims away and attaches itself to a suitable support, where it feeds and grows into an adult Hydra.

(*b*) **Sexual Reproduction**—At certain times large rounded swellings appear on the sides of the body of a polyp (see fig. 73). These are the reproductive organs. They are of two kinds—male organs (**testes**) and female organs (**ovaries**). Both may appear on the same polyp, which is then said to be **hermaphrodite.** In this case the *testes* appear on the *upper* and the *ovaries* on the *lower* part of the body, but both organs do not appear at the same time.

Both kinds of reproductive organs are at first a group of interstitial cells lying below a bulge in the ectoderm. A ripe testis contains a large number of minute *sperm cells* (*male gametes* or *spermatozoa*). Each *spermatozoon* has a tiny head of protoplasm with a nucleus, and a long thread-like tail. When ripe the testis wall bursts and the sperm cells are set free and swim away. The ripe ovary contains a single very large spherical cell (the *egg, ovum,* or *female* gamete), containing a nucleus and protoplasm very rich in food material or *yolk.* The ovum has grown by feeding on the other cells which were in the ovary. The ovary wall bursts and the ovum is exposed.' It is *fertilised* by a *spermatozoon* which swims to it and fuses with it, the nuclei of the two gametes also fusing. The *fertilised ovum* or *zygote* divides and forms a solid mass of cells (the young polyp or *embryo*). It secretes a thick horny coat and drops off into the water, where it rests for a time. Finally it develops into a young Hydra.

Only one spermatozoon is needed to fertilise an ovum, and although the spermatozoa are produced in enormous numbers most of them wander away and perish without having fertilised an ovum. Since the two kinds of gametes ripen at different times on the same polyp, the Hydra obtains the benefits of *cross-fertilisation.*

**Regeneration**—We know that if we cut ourselves new tissue soon grows and the cut " heals." Hydra possesses a

much greater power of replacing lost tissue. If a tentacle be cut from a polyp the cells of the stump multiply and a new tentacle is formed. If the body of a polyp be divided, each part will grow into a complete Hydra provided that the pieces be not too small and that each contains both ectoderm and endoderm. (Some marine *Worms* behave in the same way. Many animals possess this power of replacing lost parts, e.g. *Crabs* and *Lobsters* can grow new pincers and legs. *Star-fish* can grow new arms.) This power of replacing lost parts is *Regeneration*.

**Spirogyra: A Simple Form of Multicellular Plant**—Spirogyra is found forming tangled masses of fine slimy bright green threads floating near the surface of the water of ponds and sluggish streams. Collect and wash some of the threads, and mount a few of them in a drop of water on a glass slide.

### Experiments with Spirogyra

(1) *To observe the Form and Structure of Spirogyra*—(*a*) Examine under a low power of the microscope ($\times 25$) and

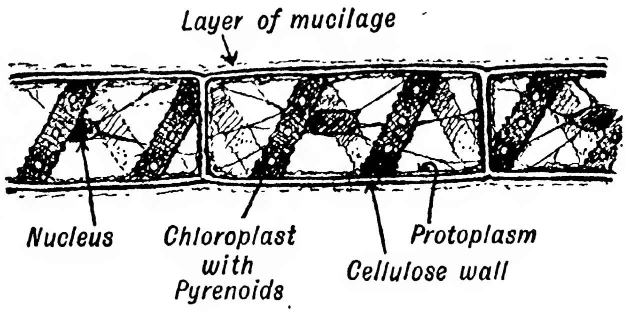



FIG. 76.—Part of filament of Spirogyra ($\times$ about 250)

sketch a filament (fig. 76). Each plant is a slender unbranched thread of cylindrical stout-walled cells, joined end to end. Each cell is crossed obliquely by a number of narrow parallel green bands. On focusing up and down, these bands are found to be parts of one spiral band winding round and round inside the cell on the inner surface of the cell-wall (see fig. 76).

(*b*) Examine and sketch one or two cells under medium

power ( $\times$ 150). Each cell has a stout cellulose wall with a thin lining of colourless protoplasm. From this lining a number of fine strands of protoplasm cross the cell-cavity to a point near its centre, where they meet to form a thin film of protoplasm which encloses and suspends a large oval

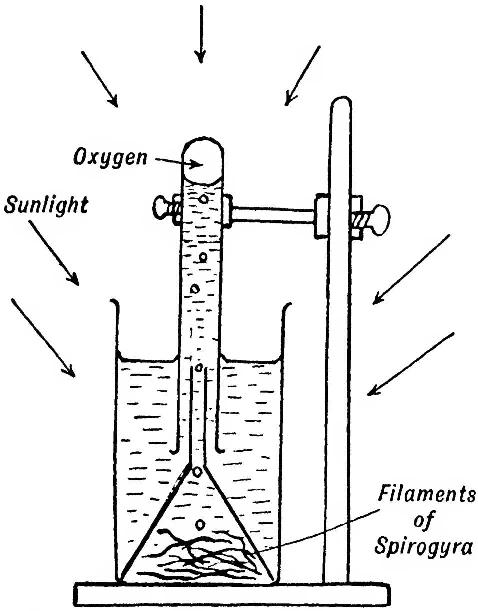



FIG. 77.—Evolution of Oxygen by Spirogyra
(an example of photosynthesis)

nucleus. A long spiral chloroplast, embedded in the protoplasm, winds from one end of the cell to the other. Rounded *pyrenoids* are embedded in the chloroplast at regular intervals. (Some species of *Spirogyra* have several of these chloroplasts, and their bands then lie closely side by side.) The cell-cavity is a large vacuole filled with clear colourless liquid (cell-sap).

**Spirogyra does not Move.**—The stout cellulose walls prevent change of shape of the cells, and there are no locomotor organs. The plant merely *floats*.

In *Spirogyra*—as in all simple green aquatic plants—the processes of feeding, digestion, absorption, and assimilation are similar to those occurring in *Chlamydomonas*. *Spirogyra* has no *contractile vacuoles* or other excretory organs. Hence waste products are excreted through the cell-wall as liquids or as Carbon Dioxide. If any solid waste matter remains—which is very doubtful—it collects as granules in the protoplasm.

(2) **To show that in Sunlight Spirogyra evolves Oxygen**—Place some threads of Spirogyra beneath an inverted funnel on the bottom of a beaker nearly full of tap-water or pond-water. Invert a test-tube full of water over the stem of the funnel (fig. 77). Leave in sunlight. Bubbles of colourless gas form and collect on the threads, and after a time rise and collect at the top of the test-tube. After some days, when sufficient gas has collected, test with a glowing splinter, which glows more brightly and may ignite. This shows that *the gas is Oxygen.*

(3) **Repeat the experiment, using (A) recently boiled and distilled Water, and (B) Tap or Pond Water, but during experiment (B) keep the Apparatus in the Dark**—No *Oxygen* is formed in these cases. This proves that the Oxygen was formed by the plant from some substance present in the tap-water and absent from the distilled water. It can be proved that this substance is *Carbon Dioxide.* It is also evident that the reaction occurs *only when the plant is exposed to light.*

(4) **To show that the Chloroplasts use the Carbon Dioxide to form Starch, but only in the presence of Light**—Take a few filaments from each of those used in experiments 2, 3 (A), 3 (B), and place each set in a watch-glass containing iodine solution. After a few minutes remove and mount each of them in a drop of water on a glass slide. Examine under a high power of the microscope.

The filaments, chosen from those used in above experiment (2), show numerous small blue granules around the pyrenoids, which themselves may also be blue. The filaments chosen from those used in experiments 3 (A) and 3 (B) contain no blue granules. This proves that the *chloroplasts have used Carbon Dioxide taken from the water and have made starch and*

*evolved Oxygen.* This process is **photosynthesis** (building up owing to the influence of light), and it is the function of the *chlorophyll* found in the green parts of all plants. The *starch* (and sugar formed from it) *is the chief food of the plant.*

**How Spirogyra Reproduces**—(*a*) A filament increases in length as a result of *simple cell-division* and subsequent growth of the daughter cells. The nucleus of a cell divides into two halves, which move apart. The protoplasm and chloroplast also divides, and a cell-wall is secreted, appearing transversely

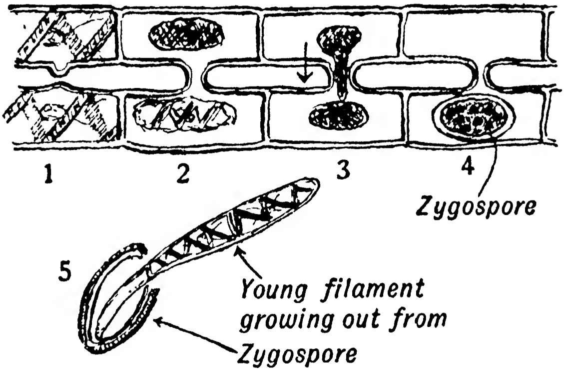



FIG. 78.—Sexual reproduction of Spirogyra

across the middle of the cell. The cells then grow to full size, causing the filament to increase in length.

(*b*) **Sexual Reproduction by Conjugation of Gametes** (fig. 78) —From time to time—especially in autumn—a pair of filaments place themselves closely side by side, possibly being held in position by a gummy secretion, and in each cell the spiral chloroplasts lose their shape and the whole cell-contents shrink away from the cell-walls and form an oval mass. Meanwhile at one point the wall of each cell bulges, grows towards, meets, and fuses with that of its neighbour, and a narrow passage unites the two cell-cavities. Through this passage the contents of one cell passes and fuses with the contents of the other cell. The moving protoplasmic mass is evidently an *active (or male) gamete,* and the stationary mass an *inactive*

(*or female*) *gamete*. The resulting *zygospore* secretes a thick outer coat, the wall of the cell bursts, and the *zygospore* floats away. After a resting period the coat of the *zygospore* bursts, and a young club-shaped filament grows out, becomes an ordinary filament and floats away.

**Each Cell of Spirogyra is a Functional or Physiological Unit,** because it can perform *all* the functions necessary for life: thus, if one cell of Spirogyra be broken from the filament it can go on living and reproducing. Usually the cells of a multicellular organism become " fixed " or " tissue " cells, specialised in structure and function, and therefore dependent upon the joint activities of the cells of the whole organism. Hence they are unlike the cells of Spirogyra and the single cell of a unicellular organism. Spiroygra, although a multicellular organism, is unlike most multicellular organisms, because each of its cells is capable of performing all the necessary activities of life, and all the cells are alike in structure. In most multicellular organisms the cells are of different kinds, each of which performs only its special functions, and is therefore dependent upon its neighbours, *i.e.* the organism is made up of different tissues each with its own characteristic structure and function.

**The Animal Cell and the Plant Cell**—Study of the foregoing simple animals and plants has shown certain resemblances and also certain differences between the animal cell and the plant cell.

**The Similarities between the Animal Cell and the Plant Cell** are: (1) Each is composed of a mass of protoplasm and a nucleus, and possesses the properties due to these. (2) Each contains particles of solid food or drops of liquid food which are used up in due course. (3) Each is capable of reproduction by division, the division of the cell always being preceded by that of the nucleus.

**The Differences between the Animal Cell and the Plant Cell** are: (1) The cell-wall of an animal cell is usually a very thin film of protoplasm firmer than, but otherwise similar to, the rest of the protoplasm (fig. 79 (*a*)). Where a thicker secreted coat is found it is **never** composed of **cellulose**. It may be chitinous, calcareous, or siliceous. The wall of a plant cell is

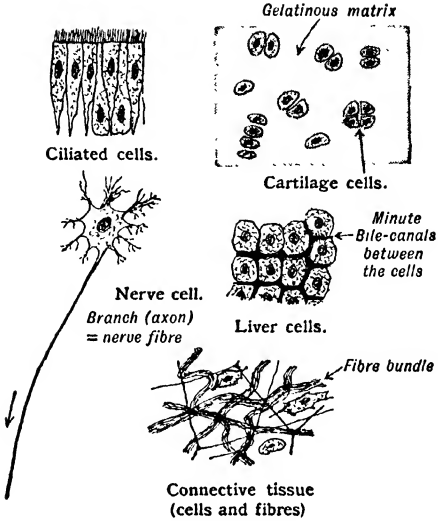



FIG. 79 (*a*).—Animal cells and tissues

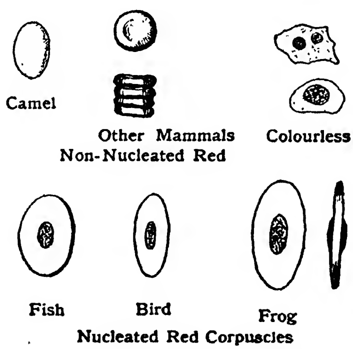
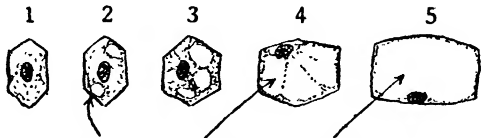
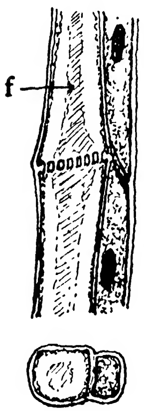



FIG. 79 (*b*).—Blood corpuscles

always thick and clearly defined and is made of cellulose (fig. 80). In some plant cells this cellulose may become coated or impregnated with other substances, *e.g.* lignin (woody) (fig. 81), or suberin (corky substance). (2) The protoplasm of




*Formation of vacuole(s) filled with sap.*
*[Cellulose wall, cell still living]*
*Stages of growth of plant cell.*




*Longitudinal and transverse sections of part of a sieve-tube and two companion cells. The tube has perforated plates, little protoplasm, and some nitrogenous and starchy food material* (f).

*Companion cells have much protoplasm. They are found in the phloem (bast) of vascular bundles.*

FIG. 80.—Plant cells

the animal cell is usually more abundant, denser, and more granular than that of a plant cell, and vacuoles, if present, are few and small.

**A Common Green Plant—the Shepherd's Purse** (a complex multicellular green plant)—When you examined *Spirogyra* you noticed: (1) All the cells were alike; (2) every cell was able to do everything needed to carry on the life and reproduction of the plant.

It was almost as if the Spirogyra plant were only a string of similar, and totally independent cells, each of which was

a self-supporting unicellular organism (like Chlamydomonas). This is unusual, and is a state of affairs found in *only* the *very simplest* multicellular organisms. If you thought of all green plants as being like Spirogyra in these respects you would have a very wrong idea of them. In *Hydra* you found that there were several kinds of cells, different in structure and in the work they did. Each did only its own special work, could not live alone, and needed other cells to do for it the things it could not do for itself. This is what is *usual* in all common multicellular organisms, whether animals or plants.

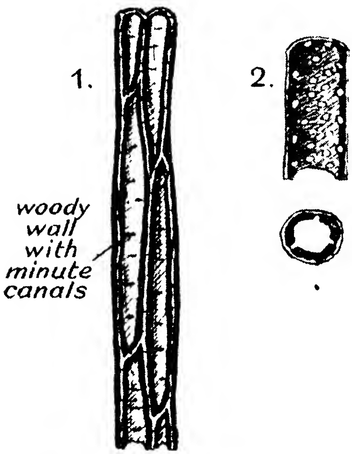



FIG. 81.—Plant tissue (wood fibres)

In order to get a true idea of the nature of a green plant we must examine some plant more complicated than Spirogyra, and we choose the common weed, which is called the *Shepherd's Purse*, because of the peculiar shape of its fruit.

*The Shepherd's Purse*—The plant is made up of a number of different parts or organs (*e.g.* stem, leaves, roots, flowers), each doing some special work, and unable to live without the others. Further, if we examine the different organs under the microscope we find in each of them many different kinds of *cells*, each again doing some particular work and all working together to carry on the life of the plant or to reproduce it. Some of the cells are concerned with taking in material to be made into food; others make up the food from this material; others, again, are joined together into tiny tubes to carry the liquid food to all parts of the plant; others with hard walls, and no protoplasm (dead cells), are merely concerned with supporting the plant and keeping its shape;

and yet others are concerned only with reproduction. This is what is found in all ordinary multicellular organisms. Groups of similar cells all doing the same work are called *Tissues*, and the organs are made up of different tissues, and the organs

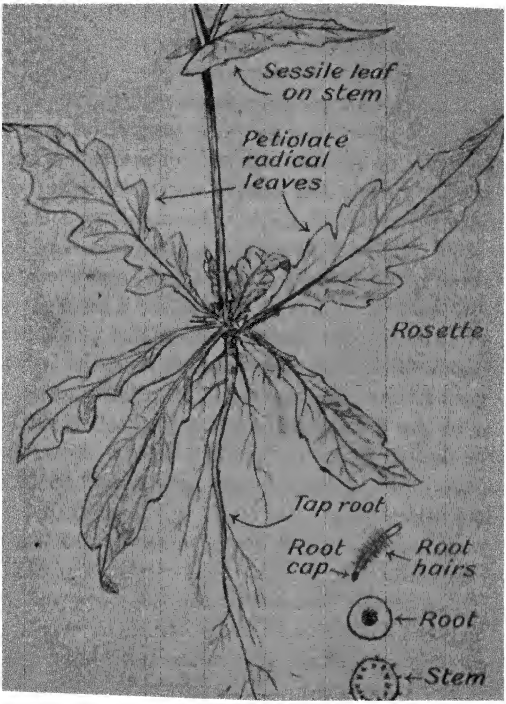



FIG. 82.—Shepherd's Purse

do different work. This we call *specialisation of function*, and the presence of different kinds of cells is called *differentiation of structure.*

*In Spirogyra there was no specialisation and no differentiation. In Hydra there was.*

We see that the plant (fig. 82) is divided into two parts, a part above the ground, green and branched and consisting of stem, branches, leaves and—at the right season—flowers and fruit. This collection we call the "shoot system." Below ground is a pale brown or nearly white branching mass of roots which we call the "root system."

*Root*—There is a main or *tap* root, tapering to a point, and bearing on its sides four rows of *secondary or lateral roots.* Note the angles at which these come off from the tap root. You will notice that each one has burst out from *inside* the tap root, and a little ring or collar marks the point at which it has come out. Also you will note that the main *root bears neither leaves nor buds but lateral roots only,* and the lateral roots also bear smaller roots like themselves. *There are two differences between the root and the shoot systems.* The roots are wavy, because they have to twist between the soil particles. *The work of the root system* is to fix the plant in the ground and also to absorb from the soil the solution of mineral salts which forms a thin film around the particles of soil. This liquid diffuses in through the cell-walls of the root, and passes to all parts of the plant until at last it reaches the leaves. If the plant be left in water two or three days, removed, and the roots examined, a number of very short delicate threads will be found near the ends of the roots. These are the *Root hairs,* and *by these alone the plant absorbs the salt solution from the soil.* The extreme tip of each root is slightly darker. This dark cap is a small thimble-like protective *root-cap* which protects the young cells of the root-tip.

*The Shoot System*—First you note that there is an upright cylindrical green stem. It is slightly hairy. It bears *branches* like itself, and these *spring from the outside of the stem,* and the branches are arranged on the stem in a spiral. Near the bottom of the stem is a rosette of leaves, each with a flat narrow oval blade deeply cut into "teeth." The flat part is the *blade,* and it is supported by a stout midrib running along the centre of the blade, and from this midrib smaller ribs or veins come off on both sides so that they form a network supporting the blade. Each leaf of the rosette is borne of a leaf-stalk or *petiole.* The angle between

the leaf and the stem is called the axil, and in each *axil* is a *bud*.

A bud is a little branch whose stem has not yet elongated, and so its young leaves are closely packed together.

This is true of the leaves borne higher on the stem, and *you can always tell a leaf by the presence of a bud in the axil* or by a *scar* if the bud has fallen off. This is often important, because some plants have peculiar leaves which do not look like leaves, and you can tell them to be leaves only because they have axillary buds. The leaves higher up the stem are at some distance apart. The length of stem separating one leaf from the next is an *internode*, and the points from which the leaves arise are *nodes* (in some plants, *e.g.* Carnation and "grasses," the node is swollen). The leaves on the stem have no petioles and are called *sessile* leaves. Note that they differ in shape from the rosette leaves and that their margins are hardly toothed at all. The *work of the leaves* is to *make food* from the simple bodies taken in by the plant and also they are the "*respiratory organs.*" All *green* parts, but particularly the leaves, make food from the salt solution which comes to them from the roots and also from Carbon Dioxide which they take in from the air through a multitude of tiny openings in the skin of all green parts, but particularly in the leaf-blades. The plant also respires through these openings or *stomata*, taking in Oxygen and giving out Carbon Dioxide made in the plant body. A large quantity of *surplus water which has passed up from the roots also passes out from the stomata as water vapour*. This is called *Transpiration*. The green colour of the leaves is due to *chloroplasts* in the cells. In sunlight these chloroplasts make food from the simple materials taken in by the plant, and this food is carried all over the plant and the cells assimilate it. If a stem be scraped with a sharp knife a number of fine strands of harder tissue arranged in a circle near the circumference are noted. On scraping the root it is found that the harder tissue forms a central cylinder. (By this arrangement of the hard tissue it is possible to distinguish a young root from a young stem. In plants with woody stems and roots this original arrangement of hard and soft tissue can be seen only if a microscope

be used.) The hard tissue is composed partly of dead cells with thickened tough walls which act as a support for the shoot or root and partly of a number of fine tubes which convey dissolved food and water throughout the plant. These strands (*vascular bundles*) are continued in the leaves as the midrib and veins.

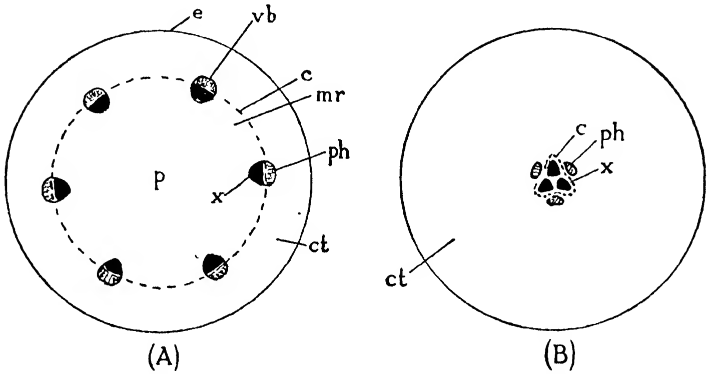



Fig. 83.—Diagram of transverse section of young (A) Stem, (B) Root

c = cambium, a band of cells which multiply, causing increased thickness; ct = cortex; e = epidermis (skin); p = pith; ph = phloem containing sieve tubes which carry food; mr = medullary ray; vb = vascular bundle (strand containing hard tissue); x = xylem (wood) containing vessels which carry water and salts. Pith, medullary rays and cortex = soft ground-tissue. In the stem each vascular bundle = phloem, cambium and xylem. In the root the xylem and phloem strands are separate and alternate, thus do not form vascular bundles.

The *Inflorescence* (fig. 84)—Near the top of the stem is a *group* of little *flowers*. This is the inflorescence.

The *Flowers*—Each flower consists of a *number of leaves* of special shape and colour. Below there is a ring of four small oval green leaves called *sepals*, which form a sort of cup protecting the rest of the flower. Because of its shape this collection of sepals is called the *calyx*. Inside the calyx is a ring of four oval leaves, each pointed at the base and of a white colour. These are *petals* and form the *corolla*. Inside

these again are six *stamens*, each consisting of a little box or *anther* (note the shape) on a long thin thread or *filament*. In the anther is a yellow powder called the *pollen*, and this is shed when the ripe anther bursts. In the centre of the flower is a little green heart-shaped case called the *ovary*. At the top of this in the " notch " is a little sticky point called the *stigma*.

Note that unlike other branches the flower-stalks do *not* stand in the axils of leaves. This is *unusual*, as you will find if you examine some other plants. Inside the ovary are twenty or more tiny round bodies. Each of these is an *ovule*, and contains an egg-cell or *ovum* (female gamete).

When a pollen grain falls on the stigma it sticks there, and a tiny thread (*pollen tube*) grows down into the ovary and bores its way into an ovule. The male cell (gamete), really little more than a *nucleus*, and having no cell-wall, passes down the tube and fuses with the ovum in the ovule. The zygote (fertilised ovum) formed is still in the ovule, which then grows and is the *seed*. The seeds become larger, and therefore the ovary swells also and is called the *fruit*. Note the peculiar shape of the fruits. When these are ripe they split and the seeds fall out and into the soil. They then germinate, and the zygote (fertilised ovum), which is now a mass of cells called the *Embryo*, develops into a young plant or *seedling*.

The *Shepherd's Purse is a common weed*, in other words it is a very *successful* plant because it can live almost anywhere —even in the poorest soil—it grows very quickly, and during most of the year it forms seeds very quickly and in large numbers, and for all these reasons it spreads very rapidly.

Now that you have examined the Shepherd's Purse you should examine a number of other plants (Pea, Dead Nettle, Buttercup), and try to find out how they resemble the Shepherd's Purse and how they differ from it and from each other. In this way you will find what features are common and what are peculiar to each plant. Thus you will get a good idea of the nature of the green plant. You will notice that each plant is made up of different parts or organs, and later you will learn what work each does and how it does it, and also of what different kinds of cells each organ is

composed. This difference of work and structure is characteristic of all except the very simplest of multicellular organisms.

**Some Differences between Animals and Plants**—In a multicellular plant such as the Shepherd's Purse, each organ has at its tip a growing point or mass of rapidly multiplying young

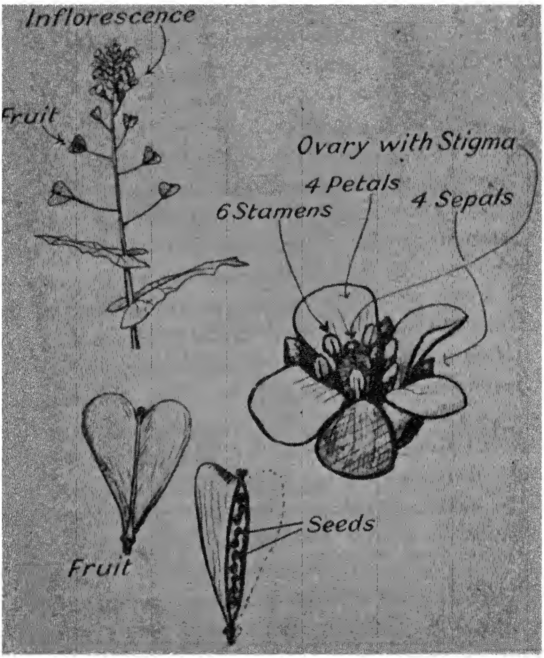



FIG. 84.—Shepherd's Purse

cells, and as fast as new cells are formed they increase in size until they are full grown. Thus the *plant is continually increasing in size.* It is always growing by the development of *new branches* from the buds, and these bear leaves, flowers, and new buds. Hence a plant *goes on branching and growing as long as it lives*, and *new organs are continually being formed.* The higher animals behave differently. They develop certain

organs or parts, each grows to full size, and no more are formed, and the animal ceases to increase in size. Thus the *body of an animal* soon reaches its final size and shape, and it is *more compact than* the body of a plant, although some plants are more compact than others. The *shape of the plant as a whole depends largely upon its method of branching.* The *longer a plant lives the more food it needs,* because it is always growing in size; but when the animal is "full grown" it does not need an increasing supply of food. You have already learned that the *cell-walls of plants consist*—at least at first—of *cellulose,* whereas the animal cell-wall *never* consists of cellulose. Again, *a plant feeds on simple inorganic (mineral) substances taken in as solutions or as gases.* An animal cannot live on such simple bodies. Its food is mainly solid and is organic (*i.e.* derived from other animals or plants), and the animal has to make it soluble (digest it) before it can be absorbed and assimilated. Again, a plant (except in a few special classes of lowly plants, *e.g.* Bacteria and Fungi) always contains chloroplasts. An animal never has chloroplasts. An animal has to seek its food, and therefore is capable of more or less locomotion, is active, and expends much energy in this way, and comparatively little in growth except when it is "young." A *plant* has to take in liquid food by its roots, and *is* therefore *fixed,* less active, and expends little energy in movement, although much energy is needed for its continual growth.

These are some of the chief differences between *most* animals and *most* plants.

## QUESTIONS

1. Describe the structure of Hydra. How does the animal feed and move?
2. What is a cell, a tissue, and an organ? Give examples of each.
3. How far is it true to say that Amœba has "organs"?
4. What are the chief differences between the animal cell and the plant cell?

5. Describe the reproductive organs and reproductive processes of Hydra.
6. Where is Spirogyra found? Describe its appearance and structure.
7. How does Spirogyra feed? How does its structure determine the nature of its food, and its mode of life?
8. Describe the reproduction of Spirogyra.
9. Describe the roots of Shepherd's Purse. What are their functions?
10. What are the chief differences between plant and animal?
11. Describe the structure and functions of a leaf and a root hair.
12. On what substances does Shepherd's Purse feed? How does it take in food?
13. Describe the flower of Shepherd's Purse. State the uses of its parts.

## CHAPTER XIII

# IRRITABILITY

**Every living organism is irritable,** because every living organism is made up of cells, which in turn are made up of protoplasm, and *protoplasm itself is irritable.*

Irritability is the ability to respond or " react " to the action of a stimulus. A *stimulus* is any external influence which acts upon an organism. The *response* made by an organism is *often a movement, but there are other kinds of responses.* We may see, hear, feel. All of these are the result of the irritability of different organs, *e.g.* the eye, ear, or skin. Sometimes we know that we are responding to the action of a stimulus, as, *e.g.*, when the mouth " waters " at the sight or smell of food. In some cases we cannot help making this response, although we know we are making it. Other responses may be taking place of which we are not aware, *e.g.* the sight or smell of food also causes the walls of the stomach to make (secrete) and pour into the stomach a fluid called gastric juice, which is then ready to digest the food if we eat it.

*A response which an organism makes* to a stimulus is a **reflex action.** Many movements are reflex, *e.g.* when we jump to avoid an oncoming motor-car.

*Every living cell is irritable,* because it can respond by " doing something " *if it receives the right stimulus.*

*When a living organism is a single cell the single cell can carry out* **all** *the activities needed to keep the organism alive, i.e.* it can move, respire, feed, grow, excrete, and reproduce. *Amœba* shows all these activities. In *a multicellular organism* which is composed of different kinds of cells, such as Hydra (fig. 75 (*b*)), a Flowering Plant, or a Man, each of *the different cells which make up the body can perform some of these activities, but not all of them.* In order to make its proper response each kind of cell must receive the proper kind of stimulus. For example, the cells of the eye must be stimulated by light

or we cannot see, and the cells of the tip of a plant-root must be stimulated by the force of gravity or the root will not grow downwards. Because each cell in a multicellular organism can do only its own particular work, it is dependent upon the other kinds of cells in the body, and they in turn are dependent upon it ; and the organism can live only so long as every kind of cell in the organism is doing its own work. When a cell performs only its special work it has some special form or structure ; for example, the muscles which move our limbs are made up of cells which are specially able to contract and expand. These cells have their own peculiar long and narrow form, and are made of a special kind of protoplasm. The cells of the stomach which make gastric juice have a different form and appearance, and are composed of a different kind of protoplasm. Thus *each kind of cell is sensitive to some special stimulus and makes some special response.*

### Experiments to observe Responses to Stimuli

(1) Dip a piece of rag or filter-paper in a weak solution of Ammonia. Keep the eyes shut and sniff the vapour. You recognise the " smell " of the Ammonia. In a few seconds your eyes " water." Here are *two* responses to the stimulus. The nerve-endings in the nose are stimulated. They carry an impulse or message to the brain, and you " recognise " the *smell* as that of Ammonia. Other nerves in the nose receive a stimulus and in turn pass a message to the cells of some bodies called " tear glands " near the corner of the eyes. These cells respond by pouring out " tears."

(2) *To obtain the " knee-jerk " reflex* (fig. 85)—Sit with the left leg crossed over the right so that the right knee fits in behind the left knee-joint and the left leg and foot hang freely.

With the edge of one hand strike the left knee a sharp blow on the tendon which runs from the knee-cap to the shin.

The left leg and foot are jerked forward and upward. This reflex *cannot* be prevented by an effort of the will.

These experiments show that *one organ may receive a stimulus to which a response may be made by another organ.* Thus the response is not always made by the part of the organism which receives the stimulus.

*This is true also of the organs of Plants.* For example, if the tip of a growing seedling of Mustard receives light only on one side, the stimulus causes the young stem to bend some distance below the growing tip, which is thereby turned towards the light (see Chapter XIV, p. 139).

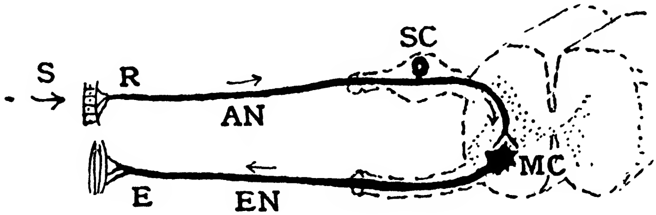



FIG. 85.—Simple reflex arc (*e.g.* for knee-jerk)

Sensory cell (receptor—R) receives stimulus (S). Impulse passes along afferent or sensory nerve fibre (AN) to the sensory centre cell (SC) of which it is a branch. The cell in the sensory centre passes impulse to motor centre cell (MC). This sends out impulse along its branch, the efferent or motor nerve fibre (EN), to the fibres of the muscle which contract. The muscle is the effector (E).

The experiments also show that **the response to a stimulus may not be a movement.**

### Experiment 1—To show that certain areas of the human skin are specially sensitive to stimuli produced by contact with other bodies

Two persons are needed to perform this experiment. The first takes a pair of " dividers " and opens the points to a distance of about $\frac{3}{4}$ in. He then presses them lightly on the inner surface of the bottom joint of the middle finger of the second person, who must not see what is being done. If the second person can feel that his skin is being touched in *two* separate points the dividers must be removed, the points brought closer together, and placed again on the same surface. This is repeated until the second person can no longer feel two points of contact. The distance between the points of the dividers is then noted. The experiment is repeated, the points being pressed against the skin of (*a*) the back of the bottom joint of the same finger, (*b*) the tip of the tongue.

The results for different persons should be written on the blackboard, and they show that the actual distances differ with different persons.

It is also found that the tip of the tongue is most sensitive, then the inner (palm) surface of the finger, whilst the back of the finger is least sensitive. **Thus (*a*) the irritability of the skin to the same stimulus is different in different places; (*b*) certain spots on the skin are specially sensitive to contact with other bodies.**

**Experiment 2—To show that different areas of the human skin are not equally sensitive to stimulation by hot or cold bodies**

Outline an area about $1\frac{1}{2}$ in. square on the back of the hand. Divide it into squares of $\frac{1}{8}$ in. side. Take a test-tube (better a metal tube) containing about 2 in. depth of hot water. Let a second person lightly touch various squares with the bottom of the test-tube and mark the spots at which the sensation of heat is most strongly felt. Repeat, using ice-cold water in the test-tube. Show the results in a diagram and compare with those obtained by other members of the class. **It is found that all parts of the skin are not equally sensitive to sensations of heat and cold.** There are small "hot" points where heat is most clearly felt, and "cold" points which are most sensitive to cold. Thus **different points on the skin vary in their irritability to heat and cold.** The exact positions of the hot and cold spots vary in different persons.

**Experiment 3—To find if all parts of the tongue are equally irritable to "sweet," "acid," and "bitter" tasting bodies**

Touch different parts of the tongue with a small brush dipped in (*a*) solution of cane sugar (1/50), (*b*) sulphuric acid (1/1000), (*c*) quinine (1/1000). Note which parts of the tongue are most sensitive to each. This experiment shows that sweet and acid tastes are most easily "tasted" by the tip and bitter tastes by the base of the tongue.

**Examples of Reflex Actions**

The following are instances of special reflex actions :—

The **Cuttle Fish** (*Sepia*) (fig. 86) when alarmed darts backward. This is caused by sudden contraction of a part of its body-wall called the mantle, which causes a sudden rush

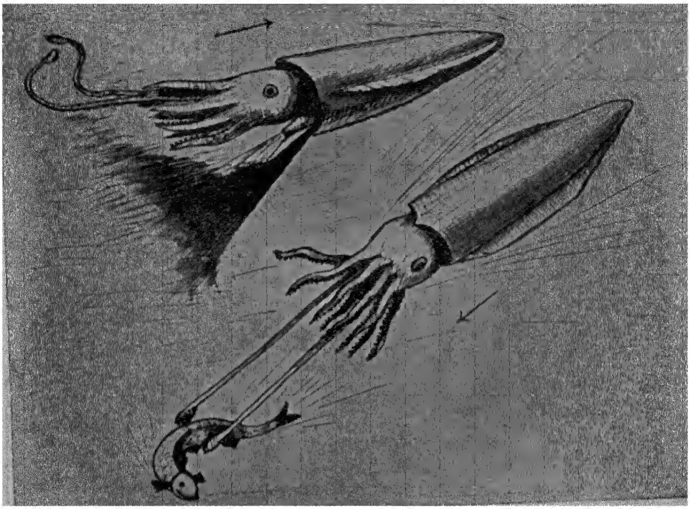


Fig. 86.—Sepia (Cuttlefish)

*Above,* sepia darting backwards and discharging jet of water and stream of ink : water from funnel, ink from ink duct.

*Below,* sepia is swimming forwards and seizing a fish. Note eight short and two long arms.

of water past the head of the animal. At the same instant the *Sepia discharges an opaque black liquid* which it has secreted and stored in a part of its body called the " ink-sac." This liquid diffuses into the water around the spot from which the animal has just darted and thus forms a dark screen between the animal and its approaching enemy. *This enables the Sepia to swim away unseen.*

The **Chameleon** (fig. 87) undergoes startling changes of colour when excited or when exposed to changes of temperature.

*It can hardly be said to have any permanent colour.* By night when quiet the colour of the skin is a dirty cream with numerous yellow patches. By day the main colour is greyish-green with scattered dark spots and a number of large brown patches on the sides of the body. When the animal is excited the brown patches become dark red-brown, and many yellow round spots appear all over the body, and these some-

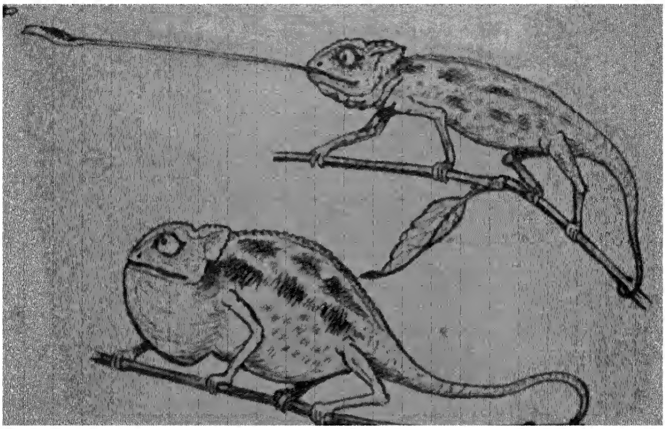


FIG. 87.—*Above,* Chameleon with tongue extended; *below,* an angry Chameleon inflates neck and body

times change to very dark green. The green colour of the body becomes brighter when the animal sits among green leaves. The colour changes are due to changes in cells containing granules and colouring matter in the skin. *The purpose of the changes is unknown.*

The **Frog** also undergoes changes of colour by the action of hormones (see p. 138) on pigment cells in the skin. The usual colours present are black, brown, and yellow. The frog becomes darker when exposed to cold, green when placed on leaves, darker when placed on a rough surface. *The changes are not due to light, but to stimulation of the skin of the feet* by the

material on which the frog is resting, *and by stimulation of the skin of the body* by changes in the temperature and moisture of the air.

Many **flat fishes** (Turbot, Flounder) undergo changes of colour of the skin of the upper surface as the fish lies on its

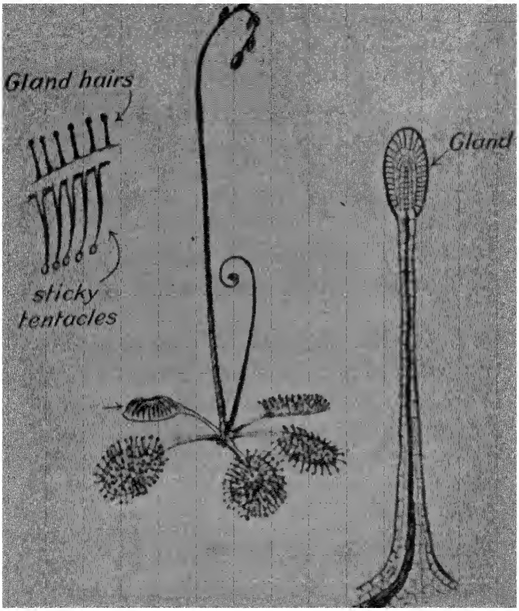



FIG. 88.—Sundew (*Drosera*) (an insectivorous plant)

other side. These changes are due to alteration in cells of the skin which contain colouring matter (black, yellow, red, or orange). *When the fish is blinded it is found that the colour changes cease.* This shows that the stimulus affects certain nerve-endings in the eye. These pass an impulse to the brain, which then sends an impulse by nerves to the pigment cells in the skin. The fish can carry out startling changes in the pattern of the spots so that the body is rendered almost

invisible when lying on a gravel or sandy sea-bottom. These changes are useful to the *fish,* as it *becomes almost invisible* to its prey or its enemies.

The **Sundew** (*Drosera*) (fig. 88) is *a small plant* growing on damp peaty moors. On the upper surface of its leaves it bears a number of tentacles, each with a rounded sticky head. If a fly alights on one of these it is held fast, the tentacles at the edges of the leaf bend inwards, the cells of the heads of a number of shorter tentacles (glandular hairs) nearer the centre of the leaf-blade pour out a fluid somewhat like the gastric juice of animals. This dissolves the soft parts of the insect and the solution is absorbed. *In this way the plant feeds.* After a time the tentacles straighten out again. The action of the tentacles is due to two sets of stimuli (contact and chemical).

These examples emphasise the fact that a **reflex action always tends to produce some result which is of benefit to the organism.**

In addition to the examples of irritability which have already been given many others will be found in the following chapters. The activities of the living organisms described in those chapters (*e.g.* Movement, Respiration, Digestion, etc.) are the result of the irritability of organs of the animals and plants concerned.

## QUESTIONS

1. What is a stimulus ? What effect does a stimulus produce on a living organism ? Give examples.
2. How would you show that your skin is " irritable " ?
3. How and why does the colour of the skin of a Frog change in certain circumstances ?
4. Give an account of any instances of peculiar irritability of plants and animals.

*Note.*—Hormones are peculiar and important chemical compounds found at times, in extremely small quantities, in the blood. Their origin and action will be described in Part III.

# CHAPTER XIV

## MOVEMENT

How can we tell if an organism is alive or not? If it moves there can be little doubt that it is alive, for *life is always accompanied by movement.* Even when no movement can be seen it is taking place within the living organism, where food material is being assimilated by living protoplasm, forming new protoplasm, and causing growth. Growth movements are constantly taking place within every living animal and plant, and will be described in detail in a later chapter.

A living organism may move from place to place—this is *Locomotion*: also one or more of its organs may change its position. Most animals are capable of locomotion, most plants are not.

The movements of living organisms may be divided into three classes:—

(1) Automatic movements.
(2) Reflex movements or involuntary movements.
(3) Voluntary movements.

Each of these will now be described in turn.

### (1) Automatic Movements

An automatic movement is caused by some chemical change within the protoplasm of the cell or organ which carries out the movement. It is not the result of any external stimulus acting on the cell or organ.

Automatic movements of the protoplasm of every living cell are constantly taking place, *e.g.* the movements of the pseudopodia of *Amœba*; the movements of the flagella of *Chlamydomonas*.

### (A) Automatic Movements of Animal Organs

(i) **The Heart**—In all animals which possess a heart pulsations of the heart-wall occur continuously during life. In some animals (*e.g.* Frog) the heart-beats continue for some time after death. This is because the death of the tissues of the heart does not take place at once. External influences, *e.g.* a sudden unexpected explosion, may alter the rate and force of the heart-beat, or they may even stop it, but they do not cause it. *The cause of the beats is within the heart-wall itself.*

(ii) **The Intestines**—The walls of the intestines (gut) of an animal are in constant movement so long as the animal is alive, although the *degree* of movement may be *influenced* by external stimuli. The movements are of two kinds: (*a*) slow swaying movements, and (*b*) a series of contractions which run like waves along the gut. The first is certainly, the second possibly, automatic. They aid the passage of food along the gut.

### (B) Automatic Movements of Plant Organs

Plant organs show a few automatic movements, which are usually slow. Growth itself is one of these, although the *direction* of growth may be *influenced* by external stimuli, such as light and gravity. The *rate* of growth of a plant organ shows automatic changes. The organ grows at first slowly, then more quickly, then slower again, and finally ceases to grow. This is called the " Grand Period of Growth," and is easily observed in the shoots and roots of young seedlings. It will be fully described in a later chapter. Although the movements of leaves are usually not automatic, but are due to the action of light and heat, the leaves of one or two plants show rapid automatic movements. For example, the leaflets of Wood Sorrel often move about a centimetre in two or three seconds, and it may be shown that light and heat neither cause nor affect these rapid movements,[1] as they do those of some other leaves, *e.g.* Clover.

[1] These rapid movements are quite distinct from those which cause Wood Sorrel to assume "day" and "night" positions, as shown in fig. 95, p. 152.

**Experiment—Examine a number of dandelion heads, some of which are in full flower, and some showing the tiny fruits each with its "parachute" of hairs at the end of a little stalk growing from the top of the fruit** (fig. 89).

*Which stalk is the longer, that on which is* (a) *the "fruiting"*; (b) *the "flowering" head?* Split the head of (*b*) downwards into two halves. Notice the disc on which the flowers are borne. *Is it flat or curved?* Repeat with (*a*). *What difference do you notice in the shape of the discs?*

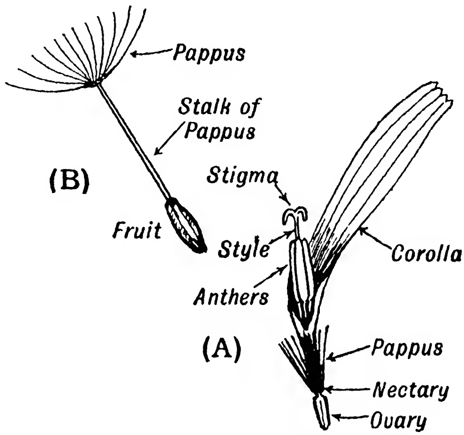


FIG. 89.—Dandelion
(A) Flower; (B) Fruit

Owing to this difference in shape the fruits, with their crown of hairs radiating like the spokes of a wheel, are more easily caught and carried away by the wind.

All of these changes, the elongation of the stalk of the "head," the alteration of the shape of the "disc," and the raising of the crown of hairs on the slender stalk, are caused by a second and rapid growth which has taken place after the flowers have been "fertilised." This second growth is the result of influences arising *within the parts of the plant*, i.e. *it is automatic.*

### (2) Reflex or Involuntary Movements, *i.e.* Movements which are Responses to External Stimuli

Examples of reflex or involuntary movements are :—

(*a*) If we touch a hot body with the hand we snatch the hand away at once. If the body be not *too* hot we can prevent this reflex withdrawal of the hand; by an *effort of will* we can *force* ourselves to keep the hand in contact with the

hot body. This is an example of the control of a reflex movement by the action of the will.

(*b*) When we sneeze we instantaneously close our eyes, and *no* effort of the will is strong enough to prevent this reflex movement of the eyelids. The action of sneezing, therefore, is accompanied by this second reflex movement which *cannot* be controlled by the will. **Reflex movements or involuntary movements are movements which the organism usually cannot help making in response to a suitable stimulus.**

So far as we know, man is the only living organism having *any* power to hinder or prevent *any* of these reflex actions. By an effort of will we are able to prevent some of our reflex actions, but most of them we cannot control.

To what extent animals can control their movements we do not know. Experiments have proved that many of the movements of animals which seem to be voluntary are really reflex. They only take place after certain stimuli act on the animals.

We do not know that plants can control *any* of their movements.

**Tropisms**—Some very simple reflex movements are performed by many of the simpler animals and by plants. These are simple bendings of the whole, or of a part of the organism either towards or away from the source of the stimulus. If the organism has the power of locomotion the bending is followed by movement along a path directly to or from the source of the stimulus. The bending is called **tropism** and the actual locomotion is called a **taxis.**

The stimulus not only *provokes* the movement as a response, but it also *directs* it.

If the Tropism or Taxis is *towards* the source of the stimulus, it is Positive ; if away, it is Negative.

## The chief External Stimuli acting upon Living Organisms and the Movements produced in Response to them

### Light and the Movements produced in Response to Stimulation by it

**Phototropism**—The bending movement caused by the action

of light is **phototropism,** and the directed locomotion is called **phototaxis.**

**Animal Phototropism and Phototaxis**—Probably the best known case of the effect of light upon the movement of animals is that of the flight of moths and other insects towards a source of light. It is well known that a moth flies towards —and even into—a candle-flame.

Whilst catching moths and insects at night you wait beside a glowing electric-torch, which exerts a great attraction for these animals. Probably you have heard of birds dashing themselves against the illuminated panes of a lighthouse-lamp.

These are examples of simple reflex movements in response to the stimulus of light. If the action of a moth is carefully studied when a bright light is switched on *two* things are noticed: (i) the moth *turns* so as to face the light; (ii) it then flies straight towards the light. The turning movement is the *phototropism*, and the locomotion which follows is the *phototaxis*.

### Experiment—To note the response of the Green Hydra to stimulation by light

Take a fairly large shallow dish—preferably of glass. Cover the sides and bottom of one half of the dish with black paper and place a lid of cardboard or black paper over that half of the dish. Place in the dish some water containing a few Green Hydra, and set it in a moderately lighted spot. After a time the polyps will be found collected in the illuminated half of the dish. (They will not do so if the light be too bright, as the animal shuns too strong a light.)

This shows that *Green Hydra moves towards the light*, i.e. *it is positively phototactic.*

*The caterpillars (larvæ) of Butterflies and Moths are usually positively phototactic, so also are Hive Bees.* Caterpillars placed " sideways " to a source of light quickly turn their heads towards it, and then turn their bodies and crawl forwards. Bees placed in a dark box into which light is admitted only through a narrow slit crawl along the path of the light towards the slit.

### Many Animals are negatively Phototactic

**Experiment—To note the movement of blow-fly maggots (gentles) when exposed to light**

Cover the lower half of a test-tube with black paper. Place the test-tube in a horizontal position and push into it a long narrow strip of cardboard on which some gentles have been placed. The gentles—*although they have* **no** *eyes*—turn their heads away from the light and move into the shaded end of the tube. This shows that the *Blow-fly Maggots are negatively phototactic.*

**Starfishes** also crawl into the shade, especially at low tide. On open sunny shores, where not even the shade of rocks can be found, Starfishes lie with the tips of their rays (arms) turned inwards to lessen the effect of the bright light. **Periwinkles** seek the darkness in rock-crevices at high tide. *Starfishes and Periwinkles* are therefore *negatively phototactic.* So also are many *burrowing Marine Worms. Sometimes conditions are such that the tropism or taxis is reversed,* e.g. *Green Hydra avoids very strong light.*

It may happen that two stimuli act at the same time on an animal, and the effect of the one to which the animal is more sensitive then overcomes the effect of the other. Thus the *Periwinkle* is usually negatively phototactic, but it is also strongly positively *hydrotactic* (moves towards water). Therefore at low tide the Periwinkle leaves the dark rock-crevices and crawls out into the light among the wet seaweeds, where it finds water—and also its food. **Nereis** (*the sand worm*) is negatively phototactic, but it also responds to continuous *contact* of surrounding objects, *i.e.* it is *positively stereotactic.* It is probably the joint result of these two taxis which causes it to burrow into the sand. If *Nereis* be placed in a dish without sand, but with part of the dish shaded, it crawls into the shade. If some narrow glass tubes be placed in the lighted half of the dish the worm leaves the shade and crawls into one of the tubes, and there it remains although the tube is brightly illuminated. The positive stereotaxis of the worm is more pronounced than its negative phototaxis.

**Phototropism of Plants**—It is well known that the upright leaves of *Hyacinth* bend towards the light if the plant be

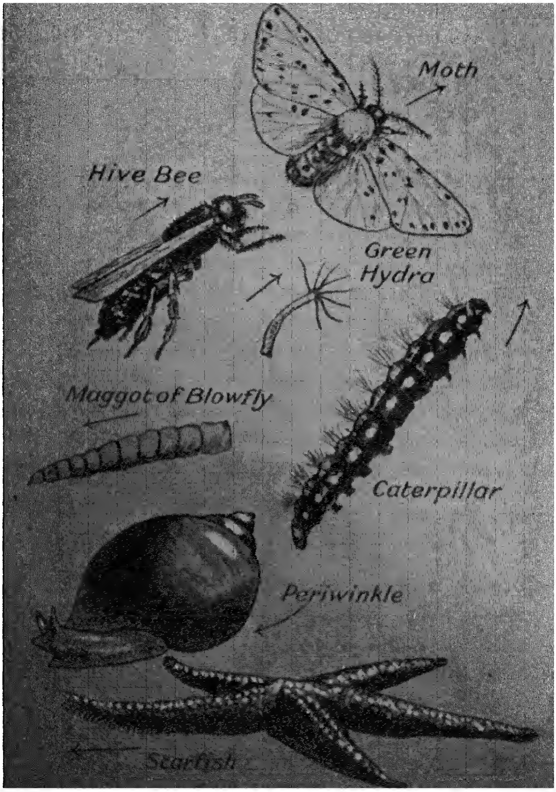



FIG. 90.—Light seekers and shade seekers

grown near a window, and we commonly find that the shoots of plants grow towards the light, and that most green leaves set themselves in such positions that they may receive the maximum amount of available light. These are instances of the phototropism of plant organs. On further examination

it soon becomes evident that some plant organs are directed towards the light, some away from it, and some nearly at right angles to it.

The following experiments provide further information concerning the light movements of plants and their organs.

**Experiment—To study the effect of light upon the movements of some small simple green plants which are capable of locomotion**

Take a large glass battery jar and cover it with black paper, leaving only a vertical slit about $\frac{1}{8}$ in. wide on one side. Place in the jar some pond-water containing a collection of small green plants such as are generally found in the green water of ponds. This will probably include the green unicellular plants Chlamydomonas, Euglena, and their allies, also Volvox and other lowly forms. Cover the top of the jar with a black paper lid, and stand it in a well-lighted spot. After a few hours it is found that the little green plants have moved towards and collected around the slit. This shows that many free-swimming green plants are *positively phototactic*.

**Experiment—To note the effect of light upon seedlings of certain " grasses "** (*e.g.* Oat, Canary Grass, Millet).

Allow Canary Grass seeds to germinate in the dark in a shallow box of loose damp earth. When the seedlings are about $\frac{3}{4}$ in. tall (*a*) leave some untouched ; (*b*) behead others, cutting off the tips at about $\frac{1}{8}$ in. from the end ; (*c*) place small tinfoil caps to cover the end quarter-of-an-inch of the tips of others. Place the box of seedlings in a large box with a small hole cut in one side just above the level of their tips. Place a lid on the box, and set it in a well-lighted spot so that the light enters the box through the hole cut in the side.

Leave for twenty-four hours, then examine the seedlings (fig. 91). It is found that :

(*a*) The untouched seedlings have bent so that their tips are directed towards the point of entry of the light, and that the region of bending of the seedling is about one-third of the distance behind the tips.

(*b*) The beheaded seedlings show no bending.

(*c*) The " capped " seedlings may show a very slight bending towards the light, although most are upright. This proves: (1) that the seedlings are positively phototropic, (2) that the extreme tip is the sensitive point which receives the stimulus, (3) that the response is made by the " shoot " (really the first leaf-sheath) some distance behind the tip, and (4) if the tip be removed the remainder of the shoot is *not* sensitive to the light-stimulus.

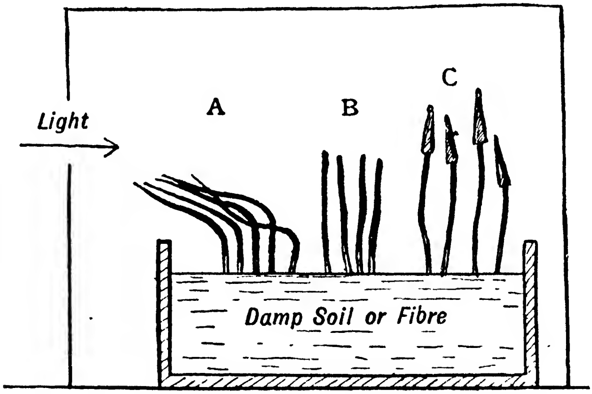



FIG. 91.—Positive phototropism of leaf-sheath (coleoptile) of canary grass

A, untouched; B, " beheaded "; C, " capped " seedlings

This and all similar *phototropic* bendings of plant organs is due to unequal growth on the two sides. The side away from the light grows more rapidly, hence the plant organ bends towards the light.

**Experiment—To note the effect of light upon the direction of growth of Mustard seedlings**

Germinate some Mustard seeds in the dark. When the young shoots and roots appear take the seedlings and place them on a narrow strip of thin cork in which a number of small holes have been pierced. Place each seedling so that its young root points down into a hole and lightly plug it in position with cotton-wool. Place the strip of cork across

the top of a small glass battery jar filled with water so that the young roots touch the water and can grow down into it (fig. 92). Place the jar under a box similar to that used in the last experiment and set it in a sunny spot. Leave for four or five days. The box must be removed from time to time in order that the water in the jar may be renewed. *This must be done as quickly as possible, and care must be taken that the positions of the cork strip and the jar are not altered.* It is found that the young shoots have bent so that the first young leaves are

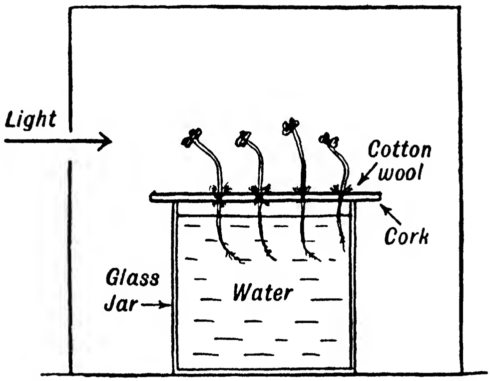



Fig. 92.—Phototropism of Mustard seedlings (Shoots—positive ; Radicles—negative)

directed towards the point of entry of the light. Note also that the roots have turned away from the light. This shows that *the shoot of the Mustard seedling is positively phototropic and that the young main root is negatively phototropic.*

**Experiment**

Another interesting experiment can be performed by growing the fungus *Pilobolus* on moist horse-dung in a similar box, but in this case a piece of ordinary glass is stuck over the hole (fig. 93). It is found that the branches of the fungus which bear the little black spore-cases turn towards the light, and that when the spore-cases are ripe they (and the tiny spores which they contain) are shot violently off against the side of

the box towards the point of entry of the light, and that many of them are found sticking to the glass. This shows

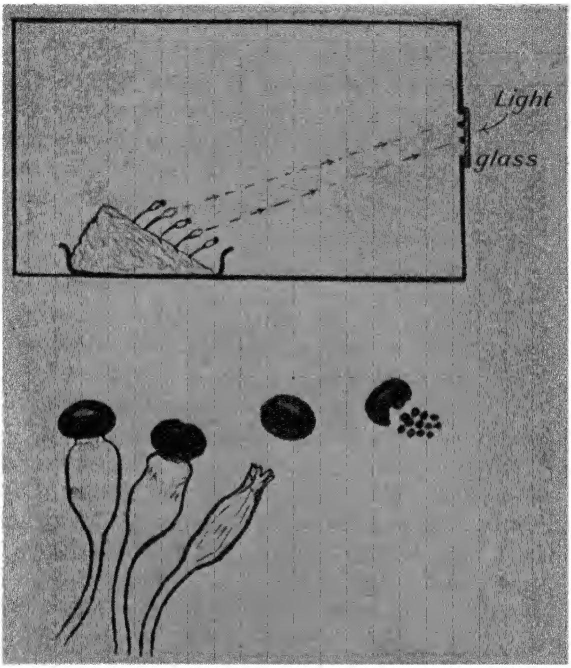



FIG. 93.

*Above.*—Pilobolus growing on damp horse-dung. Its branches bend and discharge their spore-cases towards the light.

*Below.*—Pilobolus shooting its spore-cases to the light. Note ruptured spore-cases and escaping spores.

that *the spore-bearing shoots of Pilobolus are positively phototropic.*

**Summary**

(1) Many free swimming unicellular green plants (*e.g.* Chlamydomonas, Euglena) and some simple multicellular ones (*e.g.* Volvox) swim towards the light, *i.e.* they exhibit Positive Phototaxis.

(2) The main stems of plants and the shoots of seedlings (*e.g.* Mustard), also upright leaves (*e.g.* Hyacinth), are Positively Phototropic.

(3) The spore-case bearing shoots of some Fungi (*e.g.* Pilobolus) are Positively Phototropic.

(4) Many leaves set themselves at right angles to the light, *i.e.* they are Dia-phototropic (*e.g.* Scarlet Runner).

(5) The roots of Hyacinth, the radicles of *some* seedlings, *e.g.* Mustard, and the primary roots of some plants, are Negatively Phototropic. Some plant roots are *not* sensitive to light.

### Movements in Response to Stimulation by Light, which are not Tropisms

Living organisms sometimes respond to a stimulus by an "irregular" movement which is not a Tropism or a Taxis, because it is not a bending or locomotion directly to or from the stimulus. Animals and Plants often make such "non-directed" movement as a response to *changes* of illumination.

(A) **Non-directed Movements made by Animals due to Stimulation by Light** (increase or decrease of illumination)— These movements are well shown by many marine animals both sessile (fixed) and free-moving. Many *Tube-dwelling Marine Worms* draw back their tentacles when a shadow falls upon them. *Free-moving Marine Worms* often stop abruptly when their creeping brings them to the edge of a shadow, and then they turn through 180° and creep away in the opposite direction.

Like the Starfish, the *Brittle Star* is negatively phototactic, *i.e.* crawls towards the shadow, and this often causes its wanderings to be very erratic, because it turns aside to seek every less illuminated spot near its path. The *Prawn* remains more or less quiet by day, but moves restlessly to and fro by night.

That *Owls*, *Bats*, many *Moths*, *Earthworms*, many *Carnivora*, indeed a very large number of animals, become active during the hours of darkness is well known. The necessity of capturing prey may not be the only cause of this night-prowling.

(B) **Plant Movements in Response to Stimulation by Light, but not Directed by it**—that is, the movements are not directly towards or away from the source of light.

Bright but diffuse *light causes many flowers* to *open*, and *they close during darkness*, e.g. *the Common Daisy, Winter Aconite, Coltsfoot, Crocus* (fig. 94), *Tulip, White Water Lily*, and *Wood Anemone*. Some flowers *close by day* and *open by night*, e.g. *Evening Primrose, Tobacco Plant*, and *Night-flowering Campion*. In most of the latter cases the flowers are pollinated by night-flying moths, and the flower opens when these insects are active. *In some cases change of temperature may be partly responsible for the movement*, e.g. *Tulip*. The cause of the flower movement seems to be the unequal growth of the upper and under side of the petals.

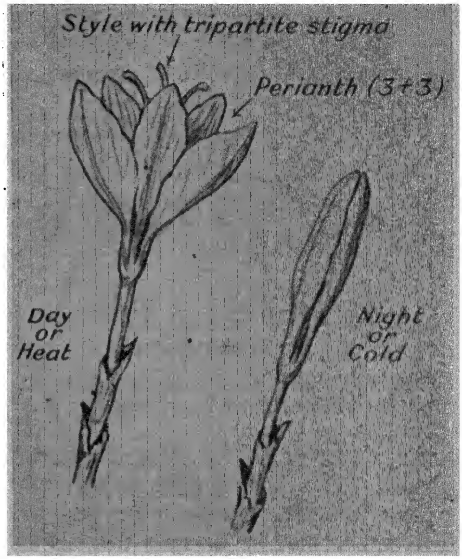



Fig. 94.—Day and night positions of Crocus. The flower also "closes" if taken from a warm to a cold room

*Some plants perform leaf-movements, often called "sleep-movements."* In the day position the leaves are opened to the sun, at night they close downwards. This is well shown by the leaflets of the leaves of *White Clover* and *Wood Sorrel* (fig. 95). In the *Clover* two of the leaflets move towards each other so that they lie face to face and the third leaflet bends over them. In the *Wood Sorrel* all three leaflets turn outwards and point downwards. In the *False Acacia* the leaflets move so that in the bright midday glare they point

vertically upwards, in moderate light they are nearly horizontal, and at night they point downwards. In all these cases the movement is brought about by changes in the water-pressure in the *pulvinus* (a small oval swelling) at the base of each leaflet. This acts as a "hinge." A possible advantage of these "sleep-movements" to the plant is that excessive deposit of dew on the leaflet is prevented.[1]

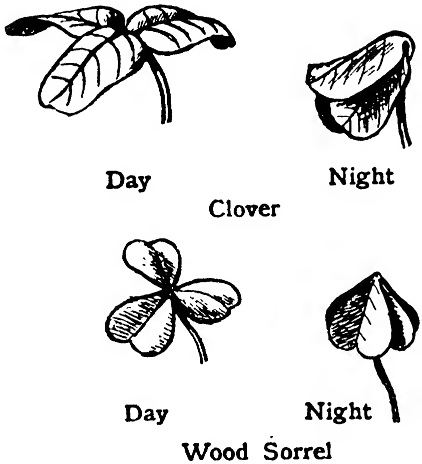



FIG. 95.—Sleep movements of leaflets of Clover and of Wood Sorrel

The shoots of many plants are longer (and often less strong) when grown in darkness or deep shade than when grown in light. The darkened sides of plant organs grow more rapidly than the lighted ones, and this is the cause of phototropic bending in many plants. This is well seen in *ivy* growing on a wall, the leaf stalks becoming so bent by this unequal growth that the leaves are turned to face the light. The growth of many young roots takes place more rapidly in red than in white light.

## GRAVITY

### Movements which are Responses to Stimulation due to the Force of Gravity

The force of gravity exerts a "pull" on every living organism as it does on every non-living body. We can readily see that most living organisms make some response

[1] The taking up of day and night positions under the influence of changes of illumination is called *Photonasty*.

to the stimulus of gravity. The most evident response is made by plants. In these the shoot (stem, etc.) bends and grows upwards, and the primary root (which we may for convenience think of as the " main " root) grows downwards.

We have seen that light acts as a stimulus causing upward growth of shoots, but shoots still grow upwards even in darkness. The pull of gravity is directly downwards; hence organs which bend and grow upwards are *Negatively Geotropic*, those which are horizontal are *Dia-geotropic*, and those which bend and grow downwards are *Positively Geotropic*. The simplest living organisms, *e.g.* unicellular animals like *Amœba* and unicellular plants like *Chlamydomonas*, do not appear to make any response to gravity, but all higher animals and plants do so.

(A) **Movements made by Animals in Response to Stimulation by Gravity**—Some fixed animals bend and grow upwards

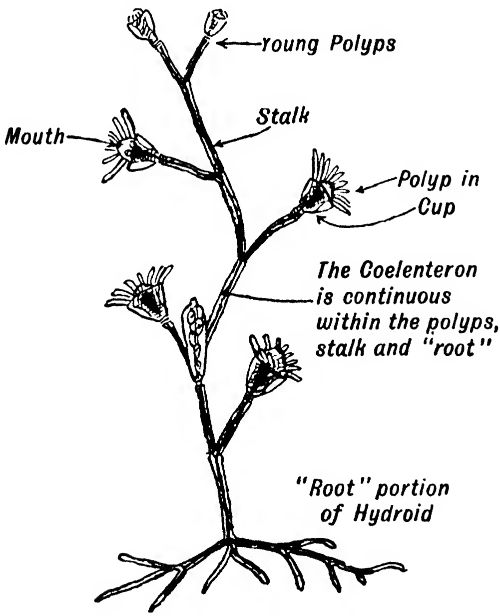



FIG. 96.—Obelia, a " colonial " hydroid

at one end just as do the shoots of plants, while their lower ends bend and grow downwards like the roots of plants. Among these are the *Hydroids* (e.g. *Obelia*), animals somewhat like Hydra, which grow in colonies borne on a stalk, with the lower end of the "stalk" forming a root-like attachment which fastens the colony of animals to rocks, etc. (fig. 96). Many *Sea Anemones* (fig. 97) show Geotropism, the "head" or "mouth" end of the animal turning away from the rocks on which it lives, *i.e.* showing Negative Geotropism, and the base or "foot" of the animal bending towards and fixing itself to the rock, etc., *i.e.* showing Positive Geotropism.

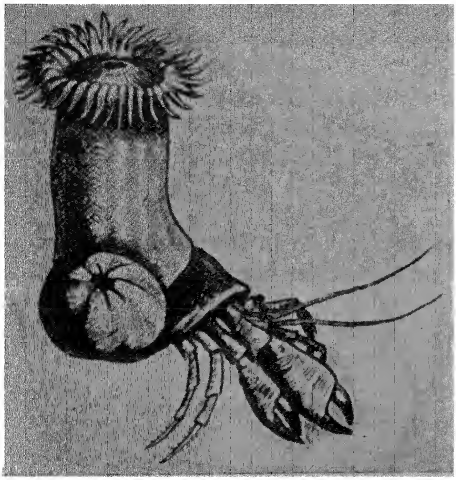


FIG. 97.—Hermit Crab in periwinkle shell with two sea anemones. The crab crawls into the empty shell to secure shelter for its soft hind-body, and "plants" young sea anemones on the shell, who keep enemies away, and obtain food from fragments which float up from the crab's pincers. This partnership benefits both animals, and is called "commensalism"

Many *Sea Anemones*, if placed in a head - downwards position, slowly bend the "head" upwards and the "foot" downwards until the animal regains its ordinary upright position. The *Sea Cucumber* shows Negative Geotaxis, *i.e.* it moves up to the top of a stone, and if the stone be turned over so that the animal is reversed it again crawls upwards to that part of the stone which is now uppermost. That this is not a case of Positive Phototaxis, *i.e.* that the animal is not crawling to the light, is shown by the fact that it performs the same movement in the dark.

Another example of animals showing *Negative Geotaxis* is

provided by *Aphides* (green fly and black fly), which crawl upwards and collect at the tips of shoots of the plants on which they live (especially the *Black Aphis* on the broad bean).

On the other hand it is commonly found that many animals, especially creeping animals, will turn aside from a more rapidly ascending slope.

*Positive Geotropism* is shown by *Earthworms, burrowing*

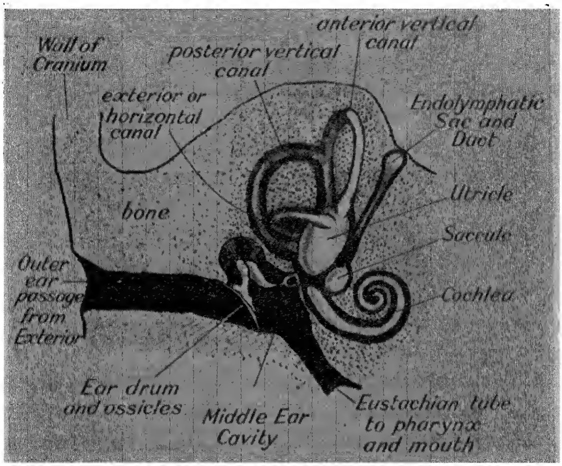



FIG. 98.—Right inner ear of man (side view) (diagrammatic)

Canals, utricle and saccule represent statocysts of lower animals, and are concerned with sense of balance. Cochlea is concerned with hearing. Branches of the auditory nerve go from all canals, utricle, saccule, and cochlea, and unite to form a single auditory nerve passing to brain. The whole organ contains liquid, and the movements of this liquid act as stimuli and " irritate " the nerve endings by means of " hairs " on the walls of the canals (etc.) and cochlea. The whole organ lies in cavity of same shape hollowed out in skull wall.

*Marine Worms* (*e.g.* Sand Worm), and some *Shell Fish*. Many animals counteract the influence of gravity by means of the pull of sets of muscles which enable the animal to " keep its balance." This sense of balance appears to depend upon the action of some " balancing organ " in the body. Many Invertebrates (animals without a backbone), *e.g.* Jellyfish, Lobsters, Crabs, Oysters, Mussels, etc., have such organs called

"statocysts." Briefly the **Statocyst** is usually a little sac containing a liquid in which are a number of little granules. These rest on the sides of the sac, and their positions are changed when the "balance" of the animal is changed. They press on the endings of nerves which go to the sac and thus produce stimuli. In response to these stimuli the animal changes its position until its ordinary "balance" is obtained. In all Vertebrates (Fishes, Amphibia, Reptiles, Birds, Mammals) the bones of the skull on each side of the head contain a sac-like structure—the inner ear—which is the organ of hearing. One part of the inner ear consists of three small semicircular tubes (semicircular canals) set in three planes at right angles to each other (fig. 98). Liquid is contained in these canals, and the movements set up in the liquid when the balance of the animal is changed, by stimulating the nerve of hearing, inform the animal of these changes of balance. It then makes the necessary movements to enable it to "regain its balance."

Other sensations, *e.g.* sight, touch, pressure, also aid the animal in securing the necessary balance, and the whole process is very complicated.

(B) **Movements of Plant Organs in Response to Stimulation by Gravity (Geotropism)**—We see that the main stem of a plant grows upwards and that the main root grows downwards, and we know that this happens no matter what may have been the position of the seed of the plant when sown. Evidently the growing *shoot has turned into a vertically upward position and the root has turned vertically downward. They have displayed Negative and Positive Geotropism respectively. That this turning is an active process* in the case of the shoot needs no proof, because the direction of growth is opposed to that of gravity. We might think that the root turned downwards passively or owing to its own weight. Let us perform an experiment to decide this point.

### Experiment—To find if the downward bending of a young root is an active process or if it is due to its own weight

Take a small shallow dish. Glue a small block of wood to the bottom of the dish, the height of the block being less than the depth of the dish. Germinate some Broad Bean seeds in

the dark, and choose one with a straight radicle (root) about half an inch long. By a pin through the seed fasten it to the top of the block so that the young root is horizontal. Pour Mercury into the dish so that it just touches the under side of the root. Pour on the mercury a thin film of water. Leave the dish in a warm dark place for forty-eight hours. Then note the position of the root-tip (fig. 99). It has dipped below the surface of the mercury. Since the density of the mercury is much greater than that of the root, the downward bending of the root cannot have been due to the "sagging" of the root owing to its own weight. An *active*

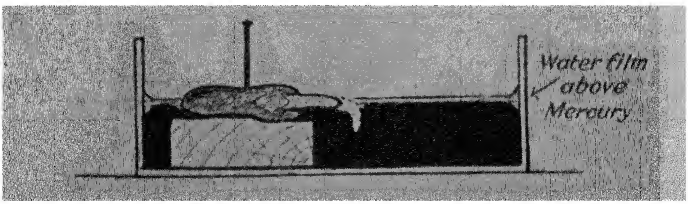



FIG. 99.—Downward bending of radicle of Bean in response to gravity-stimulus

*bending has taken place,* and the force exerted by the bending root has been enough to overcome the resistance of the mercury.

**Experiment—To find out which part of the root is sensitive to the stimulus of gravity**

Take some of the sprouted bean seeds prepared for the last experiment. With a sharp razor cut off about $\frac{1}{12}$ in. of the tip of two of the roots. Leave the beans to germinate with the roots horizontal on damp fibre. For a control place two beans with uncut roots in a similar position. Leave for twenty-four hours. The roots from which the tips have been removed show no bending. The two uncut roots have bent downwards (fig. 100). This shows that *it is the tip of the root that is sensitive to the stimulus,* and it is seen that *the bending occurs a little distance behind the root-tip.*

### Experiment—To find what part of the root responds to the stimulus of gravity

Take two of the sprouted beans, and beginning at the tip mark off the roots into 2 mm. lengths by means of a bristle dipped in waterproof Indian Ink. Allow to germinate as before. On examination it is found that in each case the distance between the tip and the first mark is practically unchanged, while the distances between the next two or three marks have greatly increased, and this is the region of bending (fig. 100). Nearer the seed the distances between the marks show less increase. This shows that the *response to the stimulus*

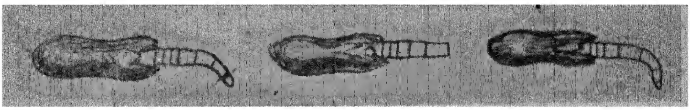


FIG. 100.—Germinating Bean seeds

*Left.*—Root tip removed and refixed with gelatine. Bending occurs.
*Centre.*—Root tip removed. No bending.
*Right.*—Root tip untouched. Bending occurs.

To show that the tip of the radicle is sensitive to (*i.e.* it is the *receptor* of) the "gravity stimulus," and that the "effector" region making responsive bending is in the growing zone behind the tip.

*of gravity received by the root-tip has taken place in the region of most rapid growth, and that this is several millimetres behind the root-tip.*

The preceding experiments show that the *roots* of the seedlings produced when the seeds germinate *are Positively Geotropic.*

### Experiment—To note the direction of growth of the young root and the young shoot of cress seedlings

Sow some Cress seeds on the surface of damp soil or fibre in a wooden box. Leave to germinate in the dark. After germination has begun examine the seedlings daily until the shoots are about 1½ in. long. Uproot them. It is found that in every case the *root has grown downwards* and *the shoot vertically upwards, no matter what was the original position of the seed.* The same results are noted if Mustard or Broad

Bean seedlings be used. Fasten a sheet of blotting-paper to a strip of box-lid. By tiny dabs of seccotine fasten the seeds of several seedlings to the paper so that the shoots and roots are horizontal. Set the strip of wood vertically in a beaker of water. Place in a dark cupboard. Note the results and give drawings at various stages.

**Experiment—To note what happens to a "grass" stalk placed in a horizontal position**

Uproot a well-grown Grass (or young Wheat) plant. Wrap the roots in wet cotton-wool. Place one of the stalks which

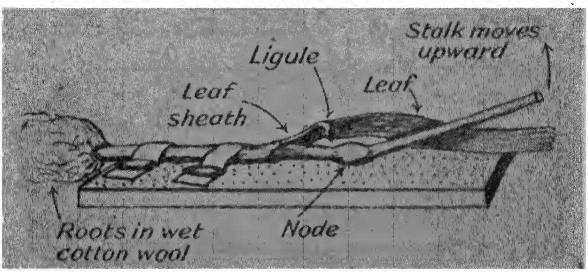



Fig. 101.—Upward bending (negative geotropism) of horizontal stalk of "grass," due to increased growth at underside of node

has well-marked "nodes" horizontally on a sheet of cork (fig. 101). Fasten it in position by strips of paper placed across the stem below a node, and fastened to the cork by drawing-pins. Cut off the stalk about 3 in. above the node, and set it aside in a dark place. Examine at the end of twenty-four and forty-eight hours. (During this time keep the cotton-wool moist.) It is found that the stalk above the node has gradually bent upwards. The bend occurs at the node. If the upward pivoting of the stalk be prevented by fastening it to the cork so that it is kept horizontal for about a week, it is found that the node has become more "bulged" at the side next to the cork. Cut the stalk and node open along the axis of the stalk in a vertical plane so that the stalk is bisected. Note that the node has thickened at the side next the cork.

This shows that (1) the *stalk is Negatively Geotropic*, (2) the upward *bending takes place at the node*, (3) *the response made by the node is increased growth on the lower side.* This accounts for the "straightening up" of Wheat and other "grasses" after they have been beaten down by a storm of wind and heavy rain.

**Experiment—To note the effect on the direction of growth of the shoots and roots of young seedlings when they are rotated** (*a*) slowly in a vertical plane, (*b*) rapidly in a vertical plane, (*c*) in a horizontal plane.

Make a simple *Klinostat*[1] as follows: Get a clock-repairer to remove the hands of a cheap clock (*e.g.* alarm clock), and

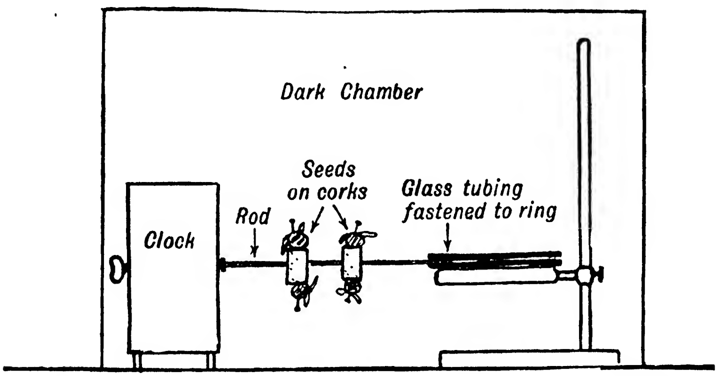



FIG. 102.—To show that when the action of gravity is neutralised there is no geotropic bending of either shoot or root

then fasten a light metal rod about 6 in. or 8 in. long to the spindle of the minute hand so that the rod is horizontal (fig. 102). Pass the rod through two fairly large thin corks and fasten these by sealing-wax or seccotine, each about an inch, to one side of the middle of the rod. Fasten a short piece of glass tubing across the ring of a retort stand so adjusted that the free end of the rod can fit loosely in the tubing, and will rotate with little friction. Around the corks

[1] Any instrument by means of which an object can be caused to rotate.

wrap strips of wet blotting-paper, which must be kept moist during the experiment. Take some *Bean* seeds which have germinated until the radicle has well developed and the young shoot has appeared. Pin the germinated seeds in various positions on the corks, about three seeds to each cork (fig. 102). Cover the apparatus with a large cardboard box or set in a dark place, and set the clock going.

(*a*) **Experiment—Slowly rotate the seeds in a vertical plane.** Examine at 24-hour intervals. It is found that *the young shoots and roots continue to grow in the directions in which they were originally pointing.* The slow rotation of the germinating seeds has " cut out " the effect of gravity because the positions of the shoots and roots have been continually changing. Thus gravity has been acting first on one and then on the other side of the shoots and roots, and the shoots have not bent upwards nor the roots downwards. This shows that **if the force of gravity is not allowed to act no bending occurs in either shoot or root.**

(*b*) **Experiment—Repeat the experiment with the seeds rotated *rapidly* in a vertical plane** by means of a klinostat,[1] and with the seeds fastened to different points on the circumference of a light disc (thin wood, metal, or stout cardboard) about 1 foot in diameter. Rapid rotation brings into operation centrifugal force, which acts outwards, and the shoots grow inwards, the effect of gravity being neutralised as before by the rotation, whilst centrifugal force is acting alone. This shows **that when the effect of gravity is neutralised by rotation, and centrifugal force is acting, the shoots grow inwards in opposition to the direction of the centrifugal force, and the roots grow outwards in the direction of the force.**

(*c*) **Experiment—Repeat, using a horizontally rotating disc.** Both gravity and centrifugal force are acting on the shoots and roots. The *shoots grow upwards and inwards, and the roots downwards and outwards.* This shows that the direction of growth has been determined by the outward pull of centrifugal force and the downward pull of gravity.

[1] Owing to the speed required, a klinostat supplied by a scientific instrument maker must be used for this experiment.

The shoots have responded negatively and the roots positively to the resultant of the two forces.

**These experiments show that the upward bending of shoots and the downward bending of roots are responses to stimulation by gravity,** and that the shoot is negatively geotropic and the root is positively geotropic. Many plants with weak stems support themselves by **twining** around nearly vertical supports (Hop, Honeysuckle). This is probably a form of Geotropism, and must not be confused with **climbing,** *e.g.* by tendrils, which is due to one-sided contact.

**Water—Hydrotropism and Hydrotaxis**

The presence of water acts as a stimulus to certain animals and to some plant organs.

The *Periwinkle* is *Positively Hydrotactic.* It will leave the dark rock crevices in which it shelters during high tide to crawl among wet seaweed during low tide, when otherwise it would be left " high and dry."

### To find out if the Roots of Plants are Positively Hydrotropic or not

**Experiment 1**—Place some Mustard seeds on the upper surface of a fairly coarse sieve or sheet of wire gauze. Cover them with a thin layer of sawdust or fibre which is kept moist. Place the sieve in a tilted position in a dark place and leave the seeds to germinate. It is found that the roots grow downwards through the meshes, and then turn and lie against the lower side of the sieve. Some of the roots turn farther and re-enter the damp sawdust. This experiment shows that **mustard roots are positively hydrotropic.**

**Experiment 2**—Allow some Bean seeds to germinate in damp soil in a wooden box, arranging the seeds near the sides of the box. As soon as the roots appear, sink a porous pot filled with water in the centre of the soil. Cease watering the soil. Leave for several days, then remove the seedlings. It is found that the roots have bent inwards towards the wet soil around the porous pot, from which water has diffused. This experiment shows that **bean roots are positively hydrotropic.**

**Contact or Pressure, and Stereotropism and Stereotaxis**

Some animals turn or move to, and some away from, the surface of solid bodies. This response is **Stereotropism.** Tube-living Marine Worms make tubes of particles of sand, etc., in which they live, others (*Nereis*) burrow into the sand like

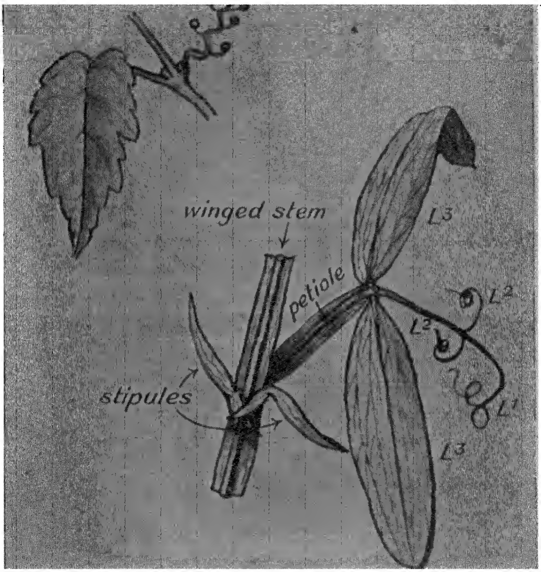



FIG. 103.

*Above.*—Virginia Creeper (leaf modified to form tendril with discs).
*Below.*—Everlasting Pea. L 1, 2, 3 = leaflets modified to form tendrils (leaflet tendrils).

the Earthworm does into the soil. The *Starfish* will cling to a stone even if the stone be turned upside down and the animal is reversed. *Paramecium* and many unicellular animals collect around solid particles of organic matter floating in water. The animals are Positively Stereotropic or Stereotactic.

*Some plant organs respond to stimulation by contact or pressure.*

Many *climbing plants* raise their leaves to the light by means of **Tendrils** (fig. 103). These are usually slender cylindrical branched or unbranched structures, *sensitive to contact*, and therefore twine around any suitable support. Some are

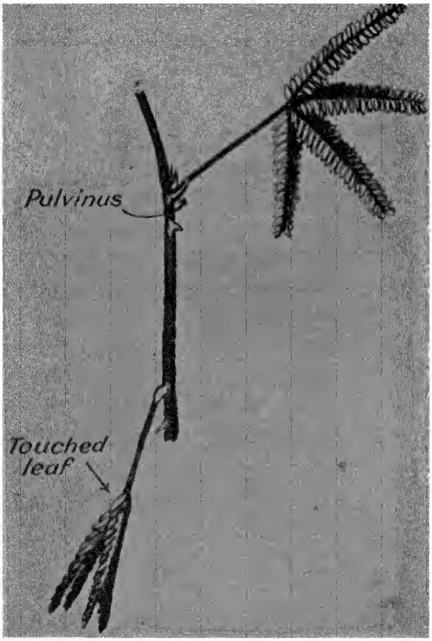



FIG. 104.—Mimosa (sensitive plant)
(The untouched leaf eventually responds)

capable of curving at only the under surface, others at both. They may be modified branches of the stem (*Vine*, *Passion flower*), bladeless leaves (*Cucumber*), or leaflets (*Pea*).

The curvature and coiling are caused by *more rapid growth on the side away from* the surface of *contact*.

The *Mimosa* (Sensitive Plant (fig. 104)) is particularly sensitive to contact. Each of its compound leaves has four leaflets composed of two rows of secondary leaflets (fig. 104). If one

of these be touched the leaflets fold together in pairs, beginning with the end pair of the touched leaflet. The four leaflets move together, and the leaf stalk bends down. This is also the "sleep position." The movements are due to pressure changes in the pulvini, which are small swellings at the bases of the leaflets, and of the leaf stalk.

A number of small organisms (*Amœba*, *Paramecium*), *Insects*, and also some plant organs (leaves of Insectivorous Plants, e.g. *Sundew*) are sensitive to *chemical stimuli*. These responses will be considered when the organisms concerned are described.

## QUESTIONS

1. Describe an experiment to show geotropism of a root of a seedling, or radicle of a germinating seed.
2. Write a short account, with examples, of the different modes of locomotion of animals.
3. What is reflex movement ? Give an example of reflex movement of a plant and of an animal.

# CHAPTER XV

## SOME OF THE CHIEF KINDS OF MOVEMENT

It is not necessary here to describe in detail the structure of those parts of the animal or plant body by which movement is effected. This will be done later when certain animals and plants are described. We must, however, briefly consider a few *types* of movement and how they are effected.

### Some Types of Animal Movement

1. *Some Movements carried out by Simple Animals.*

(a) *Amœboid Movement*—The simple movement is of the type shown by *Amœba*. In response to a stimulus the animal pushes out any part of its protoplasm as a **pseudopodium,** and thus the shape, and finally the position of the animal, is changed. The stimulus is applied directly to the responding protoplasm ; no permanent organ of movement is present, but any part of the animal may act as such.

The same kind of movement is found in some cells of multicellular animals, *e.g.* the endoderm cells of *Hydra*. The blood of the higher animals also contains a number of colourless cells (*colourless blood corpuscles*) floating in the liquid part of the blood, which perform similar movements. These cells carry food to the tissues and also attack and ingest harmful organisms (*e.g.* many *bacteria* which cause disease) which may have invaded the body of the animal. These corpuscles play a very important part in the life of every one of us and of all the animals which possess them.

(b) *Ciliary Motion*—Many animal cells are clothed with a coat of fine threads of protoplasm called **cilia.** These project through the surface layer of protoplasm which bounds the cell, and the cilia move with a continuous " lashing " motion. They bend slowly in one direction, then quickly straighten out and bend in the opposite direction. The movement passes along the surface of the animal, producing an appear-

ance such as may be seen when a breeze blows across a field of corn.

*Paramecium* is a unicellular animal which swims by means of such "ciliary" action. Instead of cilia some animals and plants possess a pair of stouter protoplasmic threads (flagella) by which movement is effected (e.g. *Chlamydomonas*).

The windpipe of man and many other animals is lined with a layer of cells which bear cilia, and by the wave-like movement of the cilia small particles of dust, etc., which have found their way with the air into the lungs and air passages are "wafted" back to the exterior.

(c) *Movement due to Contractile Changes in the Cells of Simple Animals which do not possess Definite "Muscles"*—In most animals movement is produced by the contraction and relaxation of the cells of a special tissue called **muscular tissue.** This has a structure specially suited for this purpose, and the cells are collected into definite tracts or masses called "*muscles*," *e.g.* the lean or red meat of a Cow or Sheep. In most cases (except that of the muscle of the wall of the heart), the stimulus to which the movement is a response is applied to some other organ, and from this organ a message or "impulse" passes to the muscle, which makes the response by contracting or relaxing. This message is carried by a thread-like structure called a *nerve*.

In some very simple animals (e.g. *Hydra*) certain cells have *parts* which are very contractile and will respond to a stimulus applied to the cell itself. Such are the "*muscle tails*" of the ectoderm cells of Hydra.

*Sponges* also undergo bodily movement, but not locomotion, by the contractions of certain cells. In this case the stimulus is received by a neighbouring cell which is specially sensitive, and this cell communicates an impulse (probably by some chemical means) to the contractile cell which responds.

2. *Movements which are the Result of the Contraction and Relaxation of Special Organs called Muscles* consisting of specially contractile tissue called "muscular tissue."

In most animals the chain of events which produces movement is as follows:—Some specially sensitive cell or tissue receives a stimulus. Nerves passing from this organ convey

an impulse to the muscular tissue which responds by contraction, and so movement is produced. The movement may or may not result in locomotion.

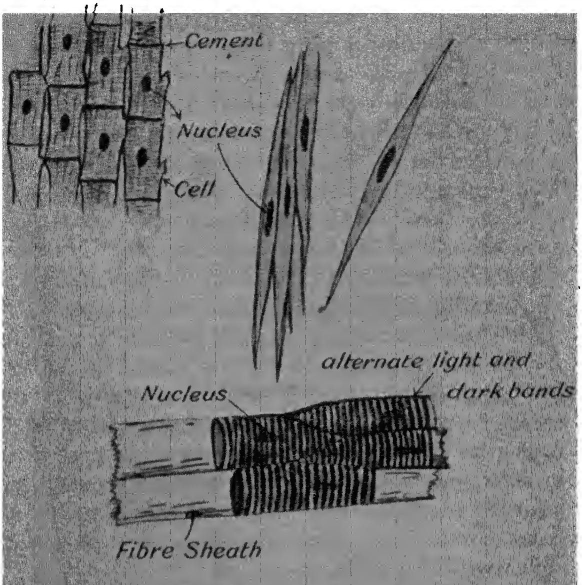



Fig. 105.—Types of muscular tissue

*Top left.*—Involuntary cardiac muscle (heart wall *only*).
*Top right.*—Plain involuntary muscle (other internal organs).
*Centre.*—Voluntary or striated muscle (skeletal muscles).
*Bottom.*—Portion of voluntary muscle highly magnified.

(a) *The Heart-beat*—The heart is a hollow organ whose walls contain muscular tissue of a special kind called "*cardiac muscle*" (fig. 105). Unlike most muscles it acts **automatically,** *i.e.* without any apparent stimulus, see p. 169. When the heart relaxes, its cavity (or cavities—for the heart is

often divided into "chambers") fills with blood which is brought to it by tubes called blood-vessels from all parts of the body, and when the heart contracts this blood is pumped out again to all parts of the body through other blood-vessels which leave the heart.

The heart-wall of the lower animals varies a good deal in structure, and will not be considered here. In all Vertebrates ("back-boned" animals, *e.g.* Fish, Frog, Reptile, Bird, Mammal) the heart-muscle is of similar type. The heart-wall consists of masses of interlaced fibres, each fibre being made up of rows of cells. Each cell is rectangular, has no sheath or cell-wall, and usually has a short side branch (fig. 105). The cell is made up of a firm kind of protoplasm which is faintly striped both transversely and longitudinally, and has a central oval nucleus. The working of the heart-muscle is *not under the control of the will*, and therefore it is called *Involuntary muscle.*

(b) *Reflex Movements carried out by Involuntary Muscle in certain other Internal Organs,* e.g. *Stomach, Intestines*—The walls of most of the organs within the animal body contain sheets of another kind of involuntary muscle called Unstriped or plain, involuntary muscle. It is capable of carrying out contractions which cause slow movements of these organs. We are usually unconscious of these movements. They are produced by stimuli which give rise to impulses carried by nerves to the involuntary muscular tissue which makes the response. Such are the churning movements of the stomach, and possibly the wavelike movements of the intestines, and the movements of the organs called "glands" which make the digestive juices and pour them into the stomach and intestines. These slow movements are usually concerned with the digestion and the passage of food along the food canal (alimentary canal).

This involuntary muscle consists of masses of tapering contractile cells cemented together (fig. 105). Each cell has a fine sheath and central nucleus, and protoplasm which is either unmarked or has only faint longitudinal stripes. These cells are very small—(less than $\frac{1}{500}$-inch long). So also are the cells of the cardiac muscle.

(c) *Movements carried out by Voluntary Striated Muscle* (fig. 106)—This muscle makes up the red or lean meat on the bodies and limbs of animals, and is called Voluntary because some of the movements are under the control of the will, although some are reflex. The same muscles of the arm may be used, *e.g.* when we pick up a book, or when we snatch the hand away from a hot body. The first is a voluntary action,

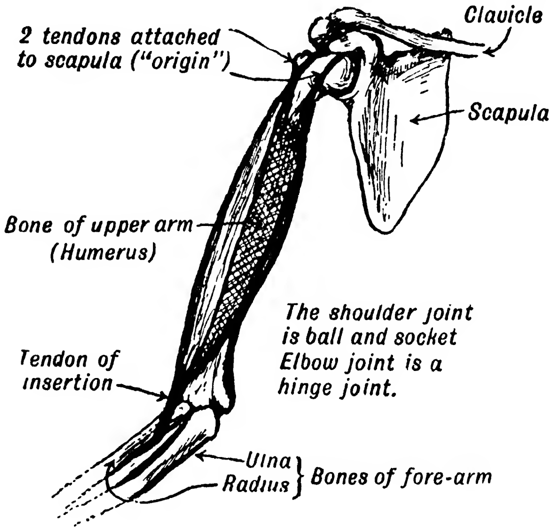



Fig. 106.—A "voluntary" or "skeletal" muscle (biceps of man)

the second is reflex. These muscles are usually attached to some rigid part of the body, *e.g.* the bones of a limb of man, or the outer shell of a lobster. They are attached by silvery threads called tendons (*sinews*) which communicate the pull of the contracting muscle to the framework of the body and so produce the movement. The movement may or may not result in locomotion. This depends upon the organs concerned and the nature of the action. The movements are *quick* and quite unlike the regular beating of the heart or the slow wave-like movements of the intestine. The voluntary muscle (fig. 105) consists of bundles of fibres bound together by a

special connective tissue—often resembling thin tissue-paper in appearance. Each fibre is cylindrical with pointed ends,

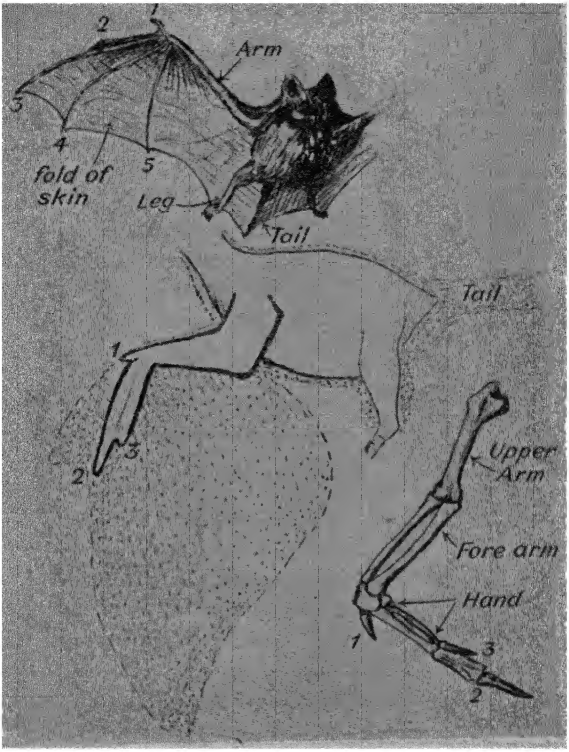



FIG. 107.

*Above.*—Wing of Bat: folds of skin between fingers and between arm, leg, tail, and body.
*Centre.*—Wing of bird: outline of feathers dotted.
*Below.*—Bones of wing of bird.

and may be as much as an inch in length but is very narrow. It is enclosed in a fine sheath, contains a number of large oval nuclei, and its protoplasm shows a large number of alternate light and dark bands, hence the name "striped" muscle.

The contraction of the muscle is made in response to impulses reaching it through nerves.

**Modes of Locomotion**—Most animals are capable of locomotion, *e.g.* by crawling, leaping, swimming, flying, climbing, walking, etc.

In most cases the organs of locomotion are projections from the wall of the body. These may be bristles, hooks, or rods

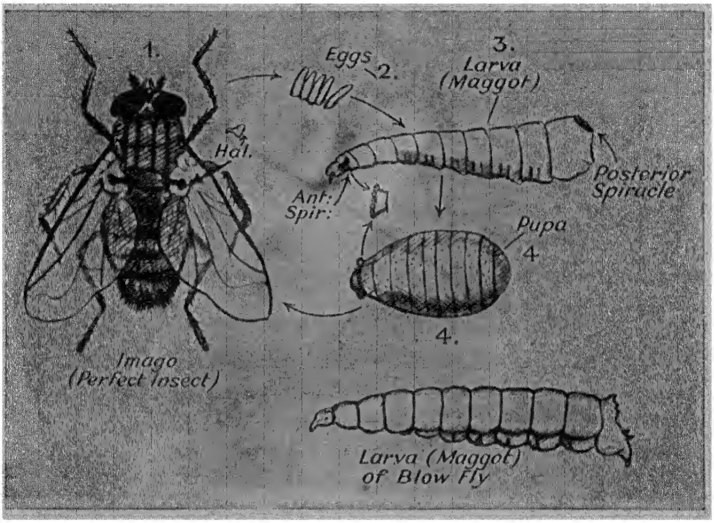



FIG. 108.—House Fly

Hal. = Halteres, a pair of rudimentary hind-wings used as "balancers."

("bristles" of Earthworm), flexible fleshy organs (foot of Snail), or jointed limbs containing muscles which move rigid levers. The levers may be bones within the limb (*e.g.* arm and leg of man), or hollow rod-like parts of an outside "shell" with the muscles within them (*e.g.* pincers and legs of lobster). No doubt you will be able to think of many other kinds of such organs. Most of the movements which produce locomotion can be placed in one of the following classes :—

(1) *Rowing movements* such as are made by a man sitting in a boat and rowing with two oars while he faces the direction

in which he is going. The Venetian "gondolier" rows his gondola in this way, although each man stands and uses only one oar. A man swimming with arms only and using the "breast stroke" makes the same kind of movements, his arms being a pair of oars. The *flight* of birds, bats, and insects is carried out in this way. The wing is generally hollowed out below and behind, and the "*effective*" stroke which propels the animal is forward and downward. Wings may be of different types. The wing of the bird is really an arm, hand, and three fingers, and bears large feathers from the elbow down, the feathers being set into the fleshy part of the limb (see fig. 107, and compare with wing of Bat). The wings of Insects are *not limbs* and have no bones (fig. 108). They are flat outgrowths of the "horny" covering or "shell" of the body-wall. Some fishes use their paired fins in the same way, but this is not the chief use of these fins—they are more useful for steering and balancing.

(2) *Sculling movements* such as those made by a man sculling a boat by means of a single oar at the stern of the boat. The oar moves from side to side and also in a sort of figure of eight movement—the eight being supposed to lie on its side. Most fishes use their tails in this way. In the case of stout-bodied fishes which cannot very freely bend their bodies (*e.g.* carp) this is the chief means of locomotion. Slender fishes (*e.g.* eel and dogfish) aid this tail movement by turning movements of the body (fig. 109 (*a*)). Other fishes (*e.g.* Skate or Ray) move by means of an up-and-down flapping and wave-like movement of a pair of enormous side fins which form a part of the flat body and which you would hardly know to be fins if you merely looked at the fish. If, however, you remove the skin and flesh you find that the flat edges of the widest part of the fish are made up of a large fin on each side, the skin of which is continuous with that of the body. This is not usual among fishes.

Other water animals, *e.g. Newts*, also move by sculling with the tail, although these animals have legs and can walk on land.

(3) *Poling movement* such as that made by a man poling or punting a boat (fig 109 (*b*)). This is the mode of loco-

motion of man and of most of the four-footed animals and " walking " animals generally. You would soon see that this is the case if you walked " stiff-legged." The limbs are usually jointed so as to give a smoother and more efficient movement.

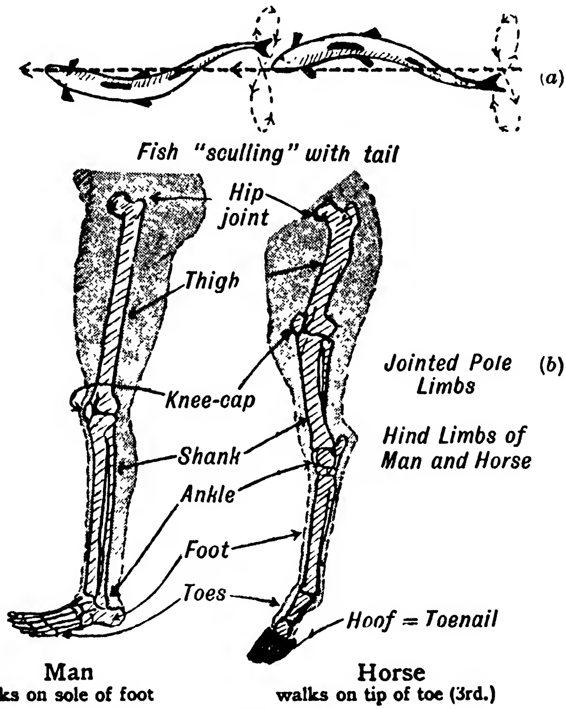



FIG. 109 (a) (b).

*Leaping animals* (Frog, Kangaroo) use similar limbs in a somewhat different fashion.

(4) *Hooking and pulling movements* such as those made by a man in pulling a boat along with a boat-hook.

This movement is seen among animals whose bodies are provided with one or more contractile " feet " provided with " suckers." The suckers get a grip on a solid surface and then pull the body along. The *Starfish* has many of these sucking feet

on the underside of its rays (arms). *Snails* and *slugs* (fig. 110) have a large muscular foot along which pass waves of contraction, and the foot grips the ground and pulls the animal along.

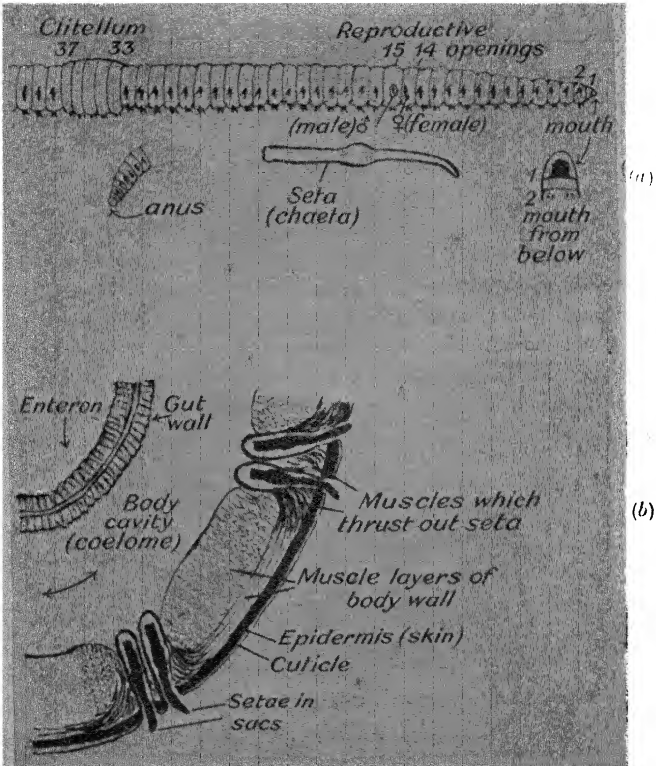



FIG. 110.—(*a*) Parts of body (of earthworm); (*b*) part of transverse section of earthworm (magnified)

The *Earthworm* has on its body two ventral and two lateral rows of short bristle-like rods set in pairs. These are bent like hooks and are made of a horny substance. Each is a "*seta*," and is set in a little sac below the skin. Muscles attached to the sac enable the seta to be thrust out to grip the

ground. The contractions of the earthworm's body enable the animal to pull itself along by means of the setæ. *Parrots* use their beaks as climbing hooks. *Snakes* have hooked scales on the belly, and these are attached to the movable

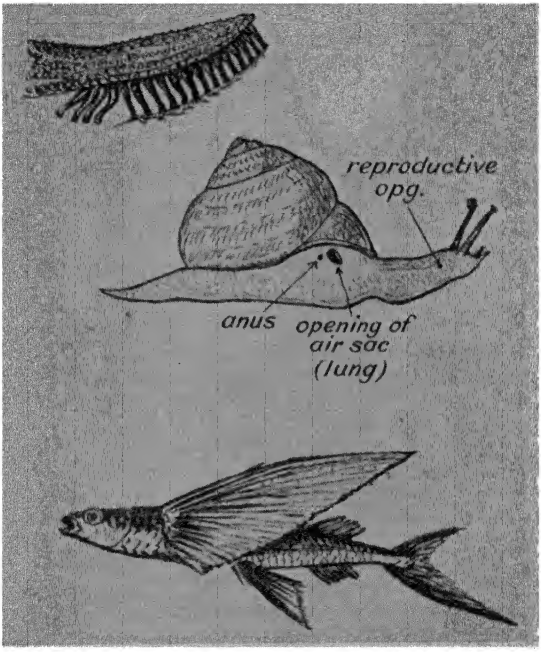



FIG. 111.

*Top.*—Part of " arm " of Starfish, with numerous sucking " tube feet."
*Centre.*—Snail : pulled along by contractions of muscle " foot."
*Below.*—Flying fish : " planes " by means of large pectoral fins.

ribs and so act as " boat hooks " to pull the reptile along. Some *caterpillars* also " loop " in a somewhat similar way.

Some animals are capable of movement by *more than one method, e.g.* the *Lobster* and *Crayfish* walk slowly forward by jointed legs, but can dart quickly backwards by sharply bending their jointed abdomen (hind-body) forwards and

downwards. *Hydra* you have seen can move in several ways *Frogs* can swim, crawl, and leap. Many *Insects* fly and walk. You will know many other instances. There are also some less usual modes of locomotion. *Sepia* swims and also darts back by contracting its mantle. The *Scallop* can crawl by means of its foot and also swims backwards by opening and *rapidly* closing (" flapping ") the two valves of its shell. The flying-fish leaps from the water by a stroke of its tail and then " planes " through the air by means of its two enormous " breast " (pectoral) fins (fig. 111). The *Jellyfish* swims by opening and partly closing its " umbrella." Indeed there are so many strange modes of locomotion that it is impossible here to give an account of more than these few of them.

**Movements of Plants**—Most of the movements of plants are either slow growth movement or they come under the heading of " tropisms " and have already been described. The slow growth movements of growing parts appear to be automatic, while tropisms are due to stimuli, as are also the " sleep movements." Most of these movements are due to unequal growth on the two sides of the plant organ which makes the movement, or to changes in the pressure of the " sap " in its cells (*e.g.* pulvinus of Mimosa). In no case is the impulse carried to the moving organ by a nerve. *Plants have neither nerves nor muscles.* When the tip of a seedling root is cut off and stuck on again with gelatine the root further back responds to the gravity stimulus by unequal growth and the root curves downwards just as if the root were intact. This shows that the impulse from the stimulated root-tip has passed across the film of gelatine to the responding part of the root (see p. 158). If there had been any nerves they would have been cut, and when nerves are cut they cannot convey any messages. Hence the message must have been conveyed by some method which enables it to pass the gelatine. We believe that it is conveyed by chemical means (*cf.* by certain dissolved substances in the cell sap) which can diffuse through the gelatine. We do not *know* that plants have any means of carrying out voluntary movements or that they have any power that we can call a " will."

QUESTIONS

1. Describe the biceps muscle of man and explain how it acts.
2. Give an account of the locomotion of some living organisms.
3. Describe the structure and action of cardiac muscle.
4. Describe the chief types of muscular tissue and explain the differences between their modes of action.
5. Sketch and describe the wing of a bird and explain how it is used.

## ANSWERS TO NUMERICAL EXAMPLES

### CHAPTER V, p. 50.

5. 20 grm.

### CHAPTER VI, p. 58.

1. (*a*) 400 ; (*b*) 80 cal.
2. (*a*) 1000 ; (*b*) 540 cal.
3. (*a*) 39·4° C. ; (*b*) 35·4° C. ; (*c*) 44·3° C.

### CHAPTER VII, p. 69.

2. (*a*) 6 cal. ; (*b*) 47·0 cal. ; (*c*) 2000 grm. ; (*d*) 400 grm. ; (*e*) 0·50 ; (*f*) 0·22.
4. (*a*) 0·095 ; (*b*) 0·18 ; (*c*) 0·036 ; (*d*) 0·061.
6. 56·2 cal. ; 0·13.
8. (i) (*a*) 5 ; (*b*) 24.
   (ii) (*a*) 4/2 ; (*b*) £1.
9. 541 cal./grm.
10. Water is about 3 times as effective as lead.

### CHAPTER IX, p. 91.

5. (*a*) 4·55° F. ; (*b*) 2·38° F.
6. (*a*) 0·64° F. ; (*b*) 390 ft.

# INDEX

## Chemistry and Physics

## (Chapters I–IX)

Acids, experiments with, 22; mineral, 19.
Alkalis, 12.

Bases, 23.
Beam balance, 4.
British Thermal Unit, 68.

Calorimeters, thick, 66.
Carbon dioxide, 30, 39; percentage of, in a carbonate, 39; properties of, 40.
Cavendish, firing globe, 14.
Chalk, 27.
Chemical compound, 10.
Cold storage, 54.
Conduction, 79; applications, 79–85; in gases, 80; in liquids, 73; in solids, 72.
Conservation of energy, 91.
Convection, 73–75, 79–85.

Deliquescent substances, 7.
Desiccator, 8.
Drying of gases, 7.

Efflorescent substances, 7.
Electrolysis of water, 13.
Elements, 9.
Energy, 88; potential, 88; kinetic, 88; forms of, 90; conservation of, 91.
Evaporation, 47–50; and cooling, 49, 80.

Ferrous sulphate crystals, 19.
Fire extinguishers, 41.
Fire screen, 78.
Force, 86.

Gas meter, 68.
Greenhouse, 78.

Hard waters, 33.
Hay-box cooker, 80.
Heat and temperature, 43–47; and energy, 86; latent, 44, 51; mechanical equivalent of, 89, 90; specific, 63–64; units, 46, 68.
Hot-water pipes, 77, 81.
Humidity, 49.
Hydrochloric acid, 21.
Hydrogen, preparation of, 12.
Hydroscopic liquids, 7.

Ice, latent heat of, 53.
Ignition point, 71.
Iron pyrites, weathering of, 19.

Kinetic energy, 88.

Land and sea breezes, 84.
Latent heat, 51, 53, 67.
Leslie's cube, 76.
Limewater, 30.

Mechanical equivalent of heat, 89, 90.
Mixtures, 9.

*Newcomen*, 56.
Nitric acid, 21.

Ocean currents, 85.
Oil of vitriol, 20.
Oxides, 23.

*Papin*, 55.
Perspiration, 50.
Petrol fire extinguished by carbon dioxide, 40.
Potential energy, 88.

Quicklime, 29.

Radiant heat, 76. 78.
Radiation, 75–85.
"Radiators," 81 ; motor-car, 83.
Reversible reaction, 17.

Salts, 23 ; preparation of, 24. 25.
*Savery*, 56.
See-saw, 2.
Soap, preparation of, 37.
Soda-water, 41.
Sodium hydroxide, 12.
Soldering iron, 80.
Specific heat, 63–64.
Spirits of salt, 20.
Steam, decomposition of, 16 ; engine, 54–57 ; latent heat, 51–53.
Sulphuric acid, 20.
Sweating record, 50.

Therm, 68.
Thermal capacity, 60–64.
Thermos flask, 83.

Vacuum flask, 83.
Ventilation, 75, 82.

Water, 11 ; analysis of, 16 ; electrolysis of, 13 ; equivalent, 67 ; formation of, 15 ; hardness of, 33 ; softening of, 36.
*Watt, James*, 56.
Weighing, rules for, 4.
Weights, box of, 3.
Winds, 84.
Work, 87.

Zeolites, 38.

## Biology

(Chapters X–XV)

Absorption, 95 ; *v.* also Nutrition.
Ammonia, 132.
Amœba, 97, 139 ff., 165.
Amœboid movement, 166.
Animal cell, 119, 121.
Anther, 127.
Aphis, 155.
Asexual reproduction, 104, 114, 118.
Assimilation, 95 ; *v.* also Nutrition.
Automatic movement, 139, 168.
Axil, 125.

Balancing organ, 155.
Bat, 150, 157, 160 ff.
Biology, 93.
Bird, 171.
Blade, 124.
Blood corpuscles, 101, 166.
Blowfly maggot, 144.
Breathing, 24 ; *v.* also Respiration.
Brittle star, 150.
Bud, 125.
Budding, 113.

Calyx, 126.
Canary grass, 146, 147.
Caterpillar (larva), 143, 176.
Cell, 108, 120, 121.
Cellulose, 102, 116, 119.
Central cylinder, 125.
Chameleon, 135.
Chemical stimuli, 165.
Chitin, 106, 111.
Chlamydomonas, 106 ff., 139, 146, 167.
Chlorophyll, 103.
Chloroplast, 102, 116, 117, 125, 129.
Ciliary motion, 166.
Clavicle, 170.
Climbing, 162, 163, 164.
Clover, 140, 151.
Cnidoblast, 111.
Cnidocil, 111.
Cœlenteron, 110, 153.

Cœlome (body cavity), 175.
Cold point, 134.
Colour changes, 135, 136, 137.
Commensalism, 154.
Conjugation, 105, 118.
Contact, 133, 163.
Contractile vacuole, 99, 103.
Corolla, 127, 141.
Crayfish, 176
Cress seed, 157.
Cross fertilisation, 105, 114.
Cuttle fish (Sepia), 135, 177.
Cyst, 150.

Dandelion, 141.
Development, 96.
Differences between animal and plant, 128.
Differentiation, 122.
Digestion, 95 ; *v.* also Nutrition.

Earthworm, 150, 155, 172, 175.
Ectoderm, 111.
Ectoplasm, 98.
Effector, 112, 133.
Egestion, 98.
Embryo, 114.
Endoderm, 111.
Endoplasm, 98.
Enteron (gut), 175.
Euglena, 146.
Excretion, 95, 99, 113.
Excretory organs, 95.
Eye-spot, 103.

False acacia, 151.
Filament, 115, 127.
Fin, 173, 174.
Fishes, 137, 173, 174, 176.
Fission binary, 99, 118 ; multiple (spore formation), 100.
Flagellum, 102, 111.
Flower, 126 ; opening by day, 151 ; by night, 151.
Food vacuole, 98.
Frog, 136, 177.
Fungi, 150.

Gamete, 105, 118, 127.
Geotropism, 153 ff.
Gland, 169.
Grasses, 146, 147, 159.
Gravity, 152.
Growth, 95, 140 ; grand period of, 140.

Hæmoglobin, 101.
Heart, 140.
Heart-beat, 168.
Hermaphrodite, 114.
Hermit crab, 154.
Hive bees, 143.
Horse, 174.
Hot point, 134.
House fly, 172.
Humerus, 170.
Hyacinth, 145.
Hydra, 109 ff., 111, 123, 143.
Hydrotaxis, 144, 162.
Hydrotropism, 144, 162.
Hypostome, 110.

Inflorescence, 126.
Ingestion, 98.
Ink sac, 135.
Inner ear, 155.
Insect, 173, 177.
Internode, 125.
Interstitial cells, 111.
Intestine, 140, 169.
Invertebrates, 155.
Irritability, 93, 103, 112, 130 ff.

Jellyfish, 155, 177.

Klinostat, 160 ff.
Knee jerk, 132.

Leaf, 124.
Lobster, 176.
Locomotion, 93, 98, 103, 112, 172 ff.
Looping, 176.

Man, 170, 174.
Marine worms, 144.
Mesoglea, 111.
Mimosa (sensitive plant), 164.
Moth, 143, 150.
Movement, 93, 98, 103, 112, 133, 139 ff., 166 ff.

Muscle, 167; biceps, 170; cardiac, 168–169; involuntary, 168–169; voluntary (striated), 170.
Muscle tails, 111.
Muscular tissue, 167–168.
Mustard seedling, 147.

Nectary, 141.
Nematocyst, 111.
Nereis, 144, 155, 163.
Nerve, 167, 177.
Node, 125, 159.
Non-directed (irregular) movements, 150.
Nucleus, 98, 116.
Nutrition, 94, 95, 98, 104, 113, 125, 129, 138.

Organ, 93, 109, 122, 132, 140.
Organism, 93, 108; multicellular, 108, 115; unicellular, 108.
Ovary, 114, 127, 141.
Ovule, 127.
Ovum, 114, 127.

Pappus, 141.
Periwinkle, 144, 154, 162.
Petal, 127.
Petiole (leaf-stalk), 124.
Photonasty, 152.
Photosynthesis (carbon dioxide assimilation), 104, 118.
Phototaxis, 143 ff.
Phototropism, 142 ff.
Pigment cells, 136–137.
Plant cell, 119.
Poling movement, 173.
Pollen grain, 127; tube, 127.
Polyp, 110, 153.
Protoplasm, 97, 102, 116, 121.
Pseudopodia, 98, 111.
Pyrenoid, 103, 116.

Radius, 170.
Receptor, 112, 133.
Reflex action, 130, 136–138.
Reflex arc, 133.
Reflex (involuntary) movement, 132, 135, 138, 139, 141 ff., 142, 149.
Regeneration, 114.
Reproduction, 96, 99, 104, 105, 113.
Respiration, 94, 99, 103, 113, 125.
Response, 131, 132.
Root, 124, 156, 162; cap, 124; hairs, 123, 124.
Rowing movement, 172.

Salt solution, 124.
Scapula, 170.
Sculling movement, 173, 174.
Sea anemone, 154.
Sea cucumber, 154.
Seed, 127, 147, 156, 158, 160, 161.
Semicircular canals, 155, 156.
Sessile, 125.
Seta, 175.
Sexual reproduction, 105, 114, 118.
Shepherd's Purse, 127 ff.
Shoot system, 124.
Signs of life, 93 ff.
Skin (human), 133, 144.
Sleep movement, 152, 165.
Snail, 172, 175, 176.
Specialisation, 123.
Spermatozoa, 114.
Spirogyra, 115 ff., 123.
Starch, 104, 106, 107, 117.
Starfish, 144, 163, 176.
Statocyst, 155, 156.
Stereotaxis, 144, 163 ff.
Stereotropism, 144, 163 ff.
Stigma, 127.
Stimulus, 93, 130; *v.* also Irritability.
Stomach, 169.
Stomata, 125.
Suberin, 121.
Sundew (Drosera), 137, 138, 165.

Tail, 171, 173, 174.
Taste, 134.
Taxis, 142.
Tear glands, 132.
Tendon, 170.
Tendrils, 164.
Tentacles, 109, 138.
Testis, 114.